MODELLING PUBLIC AND PRIVATE INVESTMENT LINKAGES IN REGIONAL DEVELOPMENT: AN OPTIMAL CONTROL APPROACH

By

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Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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This dissertation seeks to explore the role of local public policy in the creation of man-made comparative advantage of regions. Within the overall objective of portraying regional development as a comprehensive, dynamic and endogenous process, the specific policy issue of interest is the relative importance of human capital and physical infrastructure investments over the course of regional growth.

An optimal control model of a simplified two-region setting relates autonomous economic activity to local public policy in one region. The local government levies an income tax which works against its objective of maximizing regional disposable income; however, tax revenues may be spent on offsetting investments that ease infrastructural constraints and/or add to the region's stock of human capital. The government must choose the optimal combination of tax rate and expenditure shares for every period in a planning horizon.

The model is characterized by endogenous wages in two labor markets, an export sector with an exogenous price, a local sector with an endogenous price, an endogenous price deflator, and endogenous migration and private capital investment. Physical infrastructure is treated as a constraint on total regional production, and human capital investment is assumed to transform unskilled workers into skilled workers.

The model is solved numerically as a nonlinear programming problem using the General Algebraic Modeling System (GAMS) 2.25, for three different versions of the public sector, according as tax revenues are used (i) simply to maintain a fixed level of physical infrastructure (one control variable); (ii) to make net additions to the stock of physical infrastructure (two control variables); or (iii) to invest in infrastructure and/or human capital (three control variables).

The results provide some evidence in favor of an expanded role for the local government in regional growth, and suggest the need for further research on the respective roles of physical infrastructure and human capital investments in the development process.

CHAPTER 1
INTRODUCTION

1.1 Background

Over the years, uneven regional growth has prompted national, state and local governments to try a variety of development measures to improve the socioeconomic performance of lagging regions. Tax incentives and subsidies, public infrastructure investments, and special efforts to recruit 'footloose' industries attempt to promote relocation of private investment and thus to influence a region's industry mix. Public human capital investments seek to enhance the inherent productivity and adaptiveness of regions. In some countries, public manufacturing investment is tried, sometimes, as an alternative to private investment. That none of these measures has worked to satisfaction is a commonplace assertion.

Theoretical explanations of regional growth dwell more on the self-sustaining nature of growth or decline and less on the conditions that might trigger growth. As such, they are peculiarly unsuited to the policy needs of lagging regions. Dictated largely by faith, therefore, policy-makers tend to leapfrog local conditions in an attempt to duplicate the characteristics of progressively growing regions. Uniform, monolithic measures are thus supplanted onto diverse regions with highly differentiated assemblages of resources and constraints.

In order to lend credence to this claim, Sections 1.2 and 1.3 establish the descriptive orientation of regional growth theories, while Section 1.4 presents various empirical observations and notes related policy implications. Based on the material presented in Section 1.4, Section 1.5 makes the case for a discriminating, bottom-up approach to regional policy design; Section 1.6 spells out the objectives of this

dissertation, in the context of Section 1.5; and, Section 1.7 describes the organization of the remainder of the dissertation.

1.2 Theories of Regional Growth

Explanatory models of regional growth typically fall under the following categories: neoclassical, export-base, cumulative causation, and growth pole models. The one-sector neoclassical model assumes perfectly competitive product and factor (capital and labor) markets, constant returns to scale, perfect factor mobility between regions, and neutral, disembodied technical change. Initial differences in output growth between regions result from differences in technical progress, capital growth, and growth of the labor force. Given diminishing returns to capital and labor, the marginal rate of return to capital will vary inversely, and that to labor directly, with a region's capital-labor ratio. Thus, capital will move from capital- to labor-intensive, and labor, from labor- to capital-intensive, regions. Over time, therefore, regional marginal rates of return to either factor will tend to converge. While the overly aggregative nature of the neoclassical model may be blamed for its failure to fit the facts, it also has other weaknesses. The uneasy possibility remains that differential rates of technical progress could lead to enduring differences in regional growth. The model seems to make the implicit assumption that diffusion is costless and instantaneous (Armstrong and Taylor [1985], pp. 53-58; Richardson [1973], pp. 22-29).

The two-sector neoclassical model infuses some realism into its one-sector forerunner. A region is characterized by a low-productivity domestic sector and a high-productivity export sector. Following a given increase in demand in the export sector, both indigenous and migratory capital and labor move into the sector. This is in marked contrast to the one-sector model, where labor and capital necessarily move in opposite directions. Besides, different export sectors across regions can yield

different rates of technical progress and, hence, of regional growth. In general, the neoclassical assumptions of perfect information on the part of investors and workers, costless adjustment to factor price differentials, and perfect flexibility of factor prices, are taken to be unrealistic. Further, the model is solely supply-based and ignores the role of demand factors altogether. Thus, the coexistence of the domestic and export sectors is simply a matter of acceptance. Increasing returns to scale and external economies have no place in the neoclassical scheme of things (Armstrong and Taylor, pp. 59-64; Richardson, pp. 24-25).

The export-base model assumes that regions possess a highly specialized export sector. Unlike its two-sector neoclassical counterpart, however, it recognizes the linkages between the domestic and export sectors. A region's growth rate is determined predominantly by external demand for export-sector output. Regional competitiveness is decided by supply considerations like wage costs, capital costs, raw material costs, intermediate input costs and technical change. To the extent that these are favorable, growth becomes a cumulative process by virtue of the multiplier effects that result from linkages between the two sectors. It is possible that the process begets further specialization, so that the region's export profile can itself change over time. The most serious defect in the export-base model is its inability to explain the initial process of specialization--why or how do regions come to be characterized by specific export activities? The model does not spell out the conditions that influence competitiveness. Issues incidental to this concern are the role of autonomous investment and of technical change, and the possibility of capacity constraints. The model in its simplest form does not examine the implications of interregional factor movements. There are, therefore, no pointers for policy. The need to reconcile the local and export components of the same sector considerably complicates definition of the export base. The model does not focus on the determinants of export demand, like growth of income in export markets, income and price elasticities of

demand for exports, prices of substitutes and complements, and the cross-elasticities of demand for substitutes and complements. These factors are crucial to relative export performance and hence to regional growth differentials (Armstrong and Taylor, pp. 66-69; Richardson, pp. 16-22).

Kaldor [1970] points out that a region's ability to exploit its export base and thus to influence its rate of output growth per capita varies by its constituent export sectors. The potential for scale economies and progressive specialization is far greater in manufacturing than in agriculture or mining (ostensibly owing to greater product differentiation possibilities and inherent production characteristics). Kaldor takes recourse to Verdoorn's Law to describe the cumulative nature of the growth process. True to the export-base orientation, output growth is, to begin with, dictated almost entirely by exogenous growth in export demand. Verdoorn's Law states that the region's (labor) productivity growth is the sum of some autonomous component and some direct function of its output growth. As a result, even though nominal wages were to grow at the same rate in all regions, efficiency wages would decline at a faster rate in the growing regions. This would, in turn, enhance the export competitiveness of the region and make regional growth a self-generating process.

Dixon and Thirlwall [1975] attempt to present Kaldor's thesis in a more rigorous form. These efforts admittedly bring some sophistication into the simple export-base model; however, they carry forward some of the original limitations as well. The model still does not explain the type of exports in which a region will specialize; the export-base component is still rather simplistic; there is no role for local initiative in either output or productivity growth; the latter could be influenced by several factors other than mere output growth; technical progress (the autonomous component in Verdoorn's Law) may not be entirely independent of output growth. Further, relative efficiency wages need not be all-important in export performance. Nominal wages could grow faster than productivity, in prosperous regions, without blunting their competitive edge--due either to

product quality differences or to wide differences in sectoral composition across regions (Armstrong and Taylor, pp. 70-74; Richardson, pp. 30-34).

The Verdoorn Law as used by Kaldor and by Dixon and Thirlwall exemplifies the role of economies of scale in explaining regional growth differentials. But, this approach does not describe the feedback process adequately, and is anchored specifically to the export-base model. This line of reasoning allows the use of the growth pole concepts developed by Perroux [1950], Myrdal [1957] and Hirschman [1958] to describe cumulative causation as a more general process. In this reinterpreted version of Verdoorn's Law, regional productivity growth is derived not from output growth (economies of scale), *per se*, but from external economies, which are of two types: localization and urbanization, or agglomeration, economies. The former arise from the geographical concentration of plants in the same industry, through transfer or linkage economies, plant specialization, subcontracting, research and development, etc. The latter arise from the geographical association of a large variety of economic activities, through the existence of facilities jointly serving different industries, like social overhead capital, labor pools, services, etc. Whereas 'spread' effects transmit growth impulses from prosperous 'core' areas to 'peripheral' areas by opening up new investment opportunities in the latter, 'backwash' effects further impoverish peripheral areas by stimulating the migration of capital and labor into the core areas. The cumulative causation model is decidedly more articulate than any of its contenders, but falls short on a fundamental count: it does not throw adequate light on the conditions that could initiate cumulative causation (Armstrong and Taylor, pp. 76-79; Richardson, pp. 29-30, 33).

Armstrong and Taylor sum up their review thus:

> It is tempting to regard these various explanations of regional growth disparities as complementary rather than competitive. There would appear to be a strong case for fusing these approaches together in order to produce a comprehensive view of why regions grow at different rates (p. 52).

Similarly, Amos [1989] concludes that

> it is evident that each of the four theories has isolated critical aspects of regional economic growth. Since they view the process from different perspectives and concentrate on only a few of the relationships, none has combined these aspects into a comprehensive framework of regional growth. A general synthesis of these relationships should provide a more comprehensive framework that would permit an endogenous explanation of regional growth and the associated increasing inequalities (p. 6).

1.3 Endogenous Regional Growth

If the cumulative causation models--both the export-base models of Kaldor and of Dixon and Thirlwall, and the growth pole models of Perroux, Myrdal, and Hirschman--described thus far can predict regional divergence and yet be of little policy assistance, it is because they do not incorporate Amos' idea of endogenous regional growth, which may be vouchsafed as the quintessential basis for regional policy-making. Agglomeration economies help explain the endogenous scale effect in the Verdoorn Law but are not endogenous themselves. These economies may be characterized as a complex congeries of tangible (e.g., physical infrastructure, proximity to related activities) and intangible (e.g., human capital, institutional relations, cultural attitudes) attributes which serve to increase regional efficiency by both reducing transactions costs and improving resource productivity. A region which grows by virtue of cumulative causation does so because it sustains the web of tangible and intangible associations that collectively define agglomeration economies. It is in this sense that regional growth is cumulative and endogenous. There is a dynamic, qualitative dimension to agglomeration economies that the conventional concept only connotes, at best. Endogenous technical change has been studied extensively as an important facet of endogenous growth, since it makes for reduced transactions costs--both internal (through industrial reorganization) and external (through transport costs and knowledge and information transfer costs)--and for increased factor productivity (through process and product innovations).

Siebert [1969] postulates a positive relationship between a region's output level and its innovative potential, through higher investments in research and development (R & D). Time lags in the interregional diffusion of new knowledge make technical progress temporarily immobile, conferring initial advantages to the point of origin via further R & D investments in the interim. In effect, technical progress is polarized, and, in turn, polarizes capital and labor. The process is intensified by the existence of scale and agglomeration economies (Siebert [1969], pp. 40-41; Malecki and Varaiya [1986], p. 633).

According to Siebert, a region needs an effective communication system, an adequate technical horizon, and an application context (i.e., an industrial base), to be able to identify new technical knowledge generated elsewhere. Successful conversion of inventions into innovations and imitations requires sufficient investment funds (retained earnings, savings, and depreciation allowances), a viable production system, and innovative personality traits. To the extent that these characteristics are associated with larger regions, polarized growth is inevitable even if technical knowledge is interregionally mobile (pp. 69-73).

The product life cycle model moves away from the typical specification of technical progress either as disembodied or as embodied in capital. Instead, it relies on the human capital notion of technical progress, which makes labor heterogeneous between regions, depending on embodied levels of skills and education. Innovations in one region are acquired by workers in that region faster than they can diffuse to other regions, thus maintaining regional differences in productivity, investment and output. Regional wage rate differences reflect variations in human capital endowments. The early or innovation stage of a product's life cycle demands skilled labor and a high degree of investment in R & D. This stage is therefore located in the largest regions, which consequently exhibit the highest wage rates. The causation is, in fact, circular. The second, growth stage reflects less skill-intensive production and can

occur away from R & D centers. Presumably, such production will locate in medium-sized regions. The third stage is routine mass production which occurs in low-skill, low-wage (backward) regions. The model implies that the labor skills unique to any region will tend to stagnate because only jobs requiring those skill levels will be attracted to those regions. Workers cannot improve their skills by "learning by doing" in the same region (Malecki and Varaiya, pp. 634-635).

The product life cycle model contributes directly to empirical analysis of the organization of multilocational firms and the resultant effects on regional structure. In choosing appropriate locations for the different stages of their product life cycles, such firms promote a "spatial division of labor"--control functions (administration, research and development) become increasingly centralized, whereas production, often using unskilled labor, is decentralized into branch plant locations. As a result, peripheral regions undergo a progressive "deskilling" due to the continued outmigration of skilled workers associated with new firm formation. Given that skilled workers prefer to locate in higher-skill regions, technical progress polarizes regional growth. Corporate mergers and acquisitions make regional specialization a dynamic process (Malecki and Varaiya, pp. 636-637).

Malecki and Varaiya point to the importance of product innovations as opposed to the conventional preoccupation of growth models--both neoclassical and cumulative causation--with process innovations. In the export-base context, technology promotes regional export competitiveness through product innovation, by impinging on price and income elasticities of demand for the region's exports (p. 635). The resultant effects on regional structure and growth are obfuscated by the possibility that product innovations in one region may be used as process innovations elsewhere. Hence, the conclusion that "the nature of interregional competition more closely follows dimensions related to the professional-

technical labor market, rather than capital investment variations emphasized in the conventional wisdom" (p. 639).

Steiner [1987] attests to this by emphasizing the potential role of imitators as opposed to innovators, obliquely implying thereby that the product cycle theory does not touch upon the aspect of diffusion (p. 86). He also cites controversial evidence on the contention that innovation potential (and labor skill concentration) is greatest in the largest regions (p.86).

In studying locational trends in U.S. manufacturing during 1970-1977, Hansen [1979] concludes that much of the growth in the South is led by capital-intensive industries located in low-wage nonmetropolitan areas, consistent with the product cycle and spatial filtering notions (pp. 4-5). He cites similar evidence in the context of manufacturing decentralization in France (p. 5).

The product cycle framework suggests a three-tier structure of regions that is in keeping with Hansen's [1965] typology of prosperous or congested, intermediate or growing, and lagging regions (p. 5). Innovative activities keep prosperous regions in the lead, at least until they are overtaken by structural rigidities and congestion (Steiner, p. 85). Intermediate regions remain potentially viable, owing to the existence of skilled labor, process innovators, and imitators. Lagging regions, however, have no locational incentives to offer, other than low-skilled labor. They are also always vulnerable to competition from other regions which may offer even lower wages. Their economies are largely subservient to the externally-controlled operations of branch plants, and remain so. In other words, they are colonized by endogenous growth elsewhere.

Clark et al. [1986] see the contemporary geography of production in the United States as emerging directly from the strategic activities of multilocational firms. Given that all economic agents are always less than fully informed about the future, regional distribution of activity is the result of successive short-term adjustments to uncertainty. Existing

distribution of activity at any point in time, in turn, has implications for future patterns of short-run fluctuations.

Regional differentiation comes about as "corporations construct locational hierarchies which are aimed at achieving a particular distribution of economic uncertainty between labor and capital" (p. 26). As a result,

> local economies can then be differentiated along the basic dimension of economic uncertainty. Taken together as a structured set, local economies form a means for absorbing within the workforce the fluctuations and uncertainties which industrial economies generate for the productive process. Taken individually, each place, by virtue of its location within a spatial division of labor, represents a structured relation between capital and labor, which effectively sets a customary contract governing not only the level of local wages but also the pattern of how economic fluctuations are absorbed (p. 35).

Intrasectoral rather than intersectoral specialization leads to three different kinds of regions: the first kind, equivalent to the lowest tier of the product life cycle typology, absorbs the most economic variation. These regions are characterized by a marginal workforce, a high degree of external control, a spatially partitioned labor market, and a high degree of openness in terms of inward flows of intermediate goods and outward flows of products and profits (pp. 35-36). Locations for this level of activity include "not only international places providing an appropriate workforce, but also places nearer home--former agricultural communities, declining 19th-century centers, or, more subtly, suburbs or seasonal resorts" (p. 37).

The second kind of region provides some measure of insulation from economic variation. Production in such regions takes place via "processes not yet automated, reduced to assembly work or producing standardized products" (p. 36). The crucial feature of these regions is their continued reliance on skilled or semi-skilled labor.

The third kind of region, equivalent to the uppermost tier of the product life cycle theory, is the most insulated kind, and is characterized by location of product R & D, early production facilities requiring

considerable on-the-job expertise on the part of labor, and control functions (p. 36). Locations for this level of activity include "the major central metropolises providing, as they do, a variety of immediate support functions, but also a range of more complex services, such as education and access to technical expertise" (p. 37).

1.4 Policy Prescriptions

As a means to promote the endogenous growth of lagging regions themselves, Hansen [1965] recommends a changing mix of investments in social overhead (human) capital and economic overhead (physical infrastructure) capital, with initial emphasis on the former and subsequent emphasis on the latter (pp. 12-13). Coffey and Polese [1984] think of local or endogenous development as hinging on the creation of man-made comparative advantage rather than on the geographic or physical attributes of a region (p. 3). They describe the process as occurring in four stages: (i) the emergence of local entrepreneurship and the "take off" of local firms; (ii) growth of local firms beyond the region; (iii) emergence of a local control structure, with growing importance of locally controlled activity; and (iv) establishment of a locally controlled economic structure (p. 7). By implication, human capital investments represent the policy trigger. The message is echoed in Coffey and Polese [1985]:

> An awareness of the social, cultural, and political components of the development process indicates that regional policy must extend beyond capital subsidies and infrastructure investment. Martinson and Schulman, 1977, have suggested that improving a community's infrastructure in order to make it more attractive for economic relocation often has little effect upon the welfare of the indigenous population and upon its long-term productivity, unless also accompanied by policies directed at the productive and entrepreneurial capacities of the local population (p. 86).

Thus, the "people development paradigm" is seen as a necessary complement to investment in physical capital (p. 87).

At the policy level, the salutary effects of public infrastructure investment on private sector performance are almost taken for granted, although the actual mechanics are unknown. A disaggregated view of the

linkages between public and private investment is absolutely essential. Mera [1975] argues that social capital (meaning all tangible public investment expenditures) increases the overall productivity of private capital stock and labor both as an input in production and as an allocator of private factors of production. However, "the exact role of the provision of social overhead capital in enhancing the development of less-developed regions is not well known but depends upon the nature of the social capital" (p. 228). So also, Looney and Frederiksen [1981] conclude:

> There is consensus, however, as to the need for basic infrastructure facilities in potential development areas since ultimately infrastructure must be a limiting factor without which no development process could take place even if other development-inducing factors were present. However, opinions as to infrastructure's precise role in socio-economic development beyond this point differ greatly (p. 286).

Their implication is that infrastructure investments, labor market planning and educational planning must all be connected in order to achieve desirable results (p. 287). In their study of the impact of infrastructure investments on Mexico's regions during the 1960s and 1970s, they distinguish (after Hansen [1965]) between economic and social overhead capital (physical facilities, and human capital investments and services, respectively).

Killian and Parker [1991] explore the link between education and local employment growth in a cross-sectional study of metropolitan and nonmetropolitan areas in the U.S. over 1969-86. In nonmetropolitan areas, correcting the causal link for local industrial mix, local labor costs and geographical location diluted the role of education, *per se*, almost to insignificance. They therefore discount the straightforward effectiveness of educational investments in the development of lagging regions.

McNamara et al. [1988] argue that, as in the case of physical capital, stock and flow concepts must be distinguished with respect to human capital as well. Empirical studies fail to establish a strong causal link between human capital investments and local economic growth because they

tend to focus only on current educational investments, and ignore the cumulative effect of such investments on local human capital stock. Human capital stocks are defined as

> the current levels of education and skills of the workforce after migration and other adjustments to the local labor force have occurred. . . . Human capital stocks are the result of investments in primary and secondary education, health services and facilities, on-the-job training, adult education, and migration . . . Human capital stock measures should provide insight, or signals, into the level of human capital supporting the community's economy (p. 62).

Human capital flows, on the other hand,

> are the current level of human capital being produced or added to local human capital stocks through the public and private education systems, health care services and any changes in stocks created by commuting and migration which reflect adjustments to differential wages, social amenities and other incentives. . . . Empirical measures for human capital flows should be an indication of the changing stock of human capital accounting for the influence of current investments through education, health care, and migration (p. 62).

Coffey and Polese [1989] characterize producer services as "indirect elements of the production process", or, as "those intermediate demand functions that serve as inputs into the production of goods or of other services" (p. 14), and note the growing optimism of policy-makers over the potential of such services to stimulate the development of lagging regions. They note, further, that

> at the root of this optimism is the perception of these types of activities as relatively footloose; that is, they are free of the locational constraints that have made such regions relatively unattractive to investment in traditional forms of manufacturing (p. 13).

This reflects the point of view that rapid advances in communications technology make producer services highly mobile, or interregionally tradeable, activities no longer constrained by physical proximity to their markets (p. 19). This is in marked contrast to the conventional export-base view of producer services as nonbasic activities supporting an export-oriented (basic) manufacturing sector.

Coffey and Polese [1989] argue that this view rests on a simplistic, aggregative treatment of producer services[1]. They distinguish between higher-order, or front office, services requiring face-to-face contact, and lower-order, or back office, services comprising routinized and standardized functions. Empirical evidence indicates varying locational trends of more and less standardized functions; in particular, corporate control of manufacturing activity centralizes the supply of key producer services in larger urban areas, as such services thrive on human capital, inter-services linkages (urbanization economies) and infrastructure. Any decentralization of services merely imitates that of manufacturing--lower-order services catering to standardized, low-skill, branch-plant manufacturing under overall urban control (p. 16-17). Hence,

> it is locally controlled or managed firms that furnish most of the demand for locally produced business services. . . . Where the level of local control over a regional economy is low, it follows that the potential for the development of local producer services will be modest (p. 18).

They rightly conclude that regional policy must integrate measures directed at the productive and services sectors, and must take account of local resources.

Just as important as the choice of suitable policy instruments is the level at which policy is designed and implemented. Jacobs [1984] attributes the failure of macroeconomic policy to an erroneous preoccupation with the nation, which is a political and not a meaningful economic entity. According to Jacobs, cities and city regions are the proper dynamic units which decide a nation's economic identity. These are contrasted with supply regions, which are narrowly specialized, inflexible and inadaptive. Ashby [1986] endorses this new perspective and draws the implication that "economic development cannot be bought, borrowed, stolen

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[1] Marshall et al. [1987] discuss the problems involved in defining producer services, and identify a core list of industries as including advertising, market research, professional and scientific services, and research and development (p. 581). Also see O'Farrell and Hitchens [1990] for an excellent discussion of taxonomic issues.

or even given away; it must be accomplished, starting with the particular circumstances and opportunities at hand" (p. 3). And, "while the more affluent portions of nations can alleviate poverty in the poorer areas, they cannot thrust development upon these areas" (p. 4).

The importance of local-level initiative is recorded by Iliopoulou [1988]. In his evaluation of regional incentives administered by the Greek government during 1972-87 to influence the sectoral and spatial allocation of private investment, Iliopoulou observes that, rather than follow high-incentive sectors and regions, subsidized investment merely reinforced previous allocation patterns (p. 147, 149). He concludes that the findings come as no surprise, for the incentive schemes were designed to reflect national priorities, with no regard for the diverse needs and capabilities of the target regions. A more appropriate strategy would allow choice of sectors to vary across regions (p. 152).

Hansen [1990] explores the phenomenal transformation of Mediterranean France from a peripheral to a progressive region during 1975-84. There, small- and medium-sized enterprises shunned the manufacturing sector and, instead, concentrated in the business services sector. They preferred local government support to central government programs (p. 114). Hansen mentions high-quality human resources, solid linkages among local tertiary and manufacturing activities, and natural amenities, as factors contributing to rapid endogenous regional growth (p. 115).

1.5 Problem Definition

Going by the above, the failure of most policy measures would seem to stem from an oversimplified and piecemeal approach to their adoption, and a limited understanding of the linkages between regional resources, public and private investment and regional growth. At this point, the emergence of spontaneous regional patterns may appropriately be likened to a Darwinian process of natural selection, whereby survival of the fittest simply sidelines certain weaker regions from the mainstream, perhaps

permanently. Regional development policy may then be seen as akin to genetic infusions to raise their survival potential. Parasitic relationships between regions can be expected to yield to symbiotic if not generative ones. Before such infusions can be successfully attempted, however, the genetic code that is the operational structure of a regional economy must be understood.

Malecki [1987] points out that regional growth models have, as a rule, been too aggregative to pin down this code in all its complexity; that, while qualitative case studies possess considerable detail, they are too region-specific. The common thread running through them is the missing code. Regional econometric models are dynamic, and can be fairly highly disaggregated. However, they are also region-specific, and may be termed quantitative case studies. Effective policy-making calls for a body of theory that can reasonably simulate a region's spontaneous dynamics, and that can successfully unify the disparate case studies, qualitative and quantitative. Besides, such a theory should be able to account explicitly for diverse policy actions and their linkages with the region's physiology.

Given the high degree of spatial diversity even at the sub-state level, a county-level region may indeed be treated as a microcosmic economic unit, moreso since it is guided by a local government that is both a policy-maker and a fiscal appropriator, albeit within constraints laid down by state and national governments.

1.6 Research Objectives

This dissertation develops an optimal control model that links the regional growth process to conscious policy action at the regional level. The essential policy problem is the optimal dynamic allocation of internally generated public funds among various uses in the region. The proposed framework may be used to perform two analytical tasks:

(a) Regional responsiveness to local policy may be studied by comparing model solutions across alternative combinations of policy instruments, viz., by changing potential revenue-raising methods and/or expenditure types; and

(b) The crucial role of regional structure in policy design may be studied by solving the model for different regions, under a common definition of the public sector. Structural differences among regions may be incorporated in terms of sectoral mix, production technologies in each sector, labor market responses, interregional adjustment propensities of migration and private investment, and regional endowments of resources (both physical and human).

This study confines itself to task (a) above, and seeks to examine the arguments of Hansen [1965] and Coffey and Polese [1984], as to the relative importance of human capital and physical infrastructure investments over the course of endogenous regional growth.

1.7 Organization of the Study

Chapter 2 reviews past applications of optimal control to questions of regional growth, with particular emphasis on the role of the public sector and definition of regional structure. Chapter 3 contains a detailed relational description of the proposed framework; a simplified two-region setting is used to illustrate the dynamic links between various aspects of the public and private sectors. Chapter 4 uses specific policy variables and functional forms to arrive at a particular case of the general model of Chapter 3; the model is then calibrated for a hypothetical economy so as to facilitate its numerical solution. Chapter 5 is a comparative treatment of the results pertaining to three different versions (scenarios) of the public sector. Chapter 6 summarizes the major contributions of the study, and makes suggestions for further research. Appendix A reports the results by scenario in tabular form, while Appendix B

presents the behavior of important variables across scenarios, in graphical form.

CHAPTER 2
OPTIMAL CONTROL MODELS OF REGIONAL GROWTH--A PERSPECTIVE

2.1 Background

Regional policy analysis often takes the form of mathematical programming wherein the general conceptual processes described by the various regional growth theories are represented as formal sets of relationships among various economic variables (or indicators), such as welfare or utility, production, consumption, investment, savings, capital, income, employment, unemployment rate, etc. Policy variables, such as taxes and public expenditures, are included as exogenous (or independent) variables which affect the regional economy in specified ways. Simulations are conducted over the policy variables to derive conclusions about the region's policy responsiveness. Optimal control models go beyond the typical mathematical programming framework in seeking to optimize the policy variables over time in the interest of some stated political objective(s)[1]. Bennett and Hordijk [1986] observe that "whereas simulation methods applied to policy appraisal tell us "what happens if", optimal control seeks an answer to the alternative question "to achieve a given policy target, how should policy instruments be set?"" (p. 424).

An optimal control model, besides being dynamic, is by construction a representation of the policy problem in perspective. It specifies policy objectives, control variables that can be manipulated to achieve those objectives, and a set of state variables and their interrelationships that describe the regional economy and constrain the decision-maker. The dynamic behavior of the system is specified in terms of "equations of

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[1] For a discussion of the fundamentals of optimal control theory, see Intriligator [1971], Chapter 14, pp. 344-369.

motion" of the state variables. The regional structure may be made general enough to accommodate diverse regions. Optimal control models can differ from one another in terms of the stated objectives as reflected in the objective functional, the choice of policy variables that impinge directly or indirectly on those objectives, and the degree of detail used in describing regional structure and interregional linkages (factor and commodity flows between regions, and the transmission of impacts across regions). Here, differences can arise both over the number and combination of the economic variables of interest, and over the complexity of the relationships among those variables.

In terms of specifying the objective functional, Friesz [1977] identifies seven categories of objectives that might potentially influence regional public investment decisions: (i) consumption; (ii) time-stream of income; (iii) end-of-period income; (iv) income growth rates; (v) acceleration of income growth rates; (vi) interregional equity; and (vii) wages (pp. 123-126). Wu [1987] adds (i) maximization of total capital stock at the end of the planning period; (ii) minimization of the time taken to attain a certain level of total capital stock; and (iii) minimization of environmental deterioration (p. 48). It is also possible to incorporate conflicting objectives (for example, growth versus equity, or environmental quality versus growth) within a composite, multiobjective criterion functional that is essentially a weighted average of the individual objectives; the relative weights are meant to reflect the political priorities of the decision-maker. Besides the growth equations of the state variables, control variable constraints and other policy limitations may be included as auxiliary constraints. Examples of these are (i) definitional constraints (the equity objective), (ii) minimum service requirements to be met from public funds, (iii) "pay-own-way" constraints on regions, (iv) tax rate constraints, (v) cost-sharing constraints, (vi) constraints on government debt, and (vii) constraints to ensure balanced growth (Friesz, pp. 128-31).

The earliest optimal control models of regional growth were straightforward applications of national-level models at the regional level; in depicting regions as aggregative closed economies, they ignored interregional phenomena, and were structurally limited to one or two state variables and single-objective criterion functionals. Nijkamp et al. [1986] note that

> the first approaches to modeling the regional economy were essentially a natural and logical extension of modeling efforts at the national or international level. In a manner analogous to the national macro model design, models were developed for single regions (states, urban areas, counties, etc.). These models aimed at assessing the impact of regional or nationwide policies at a regional scale. By trying to replicate the national economy at a regional level, most regional economists used a so-called top-down approach, so that the national economy was assumed to be given for the regional model without allowing for a feedback influence. . . . Most single-region economic models focused on the evolution of a limited number of variables: production output, employment, income, tax revenues, public expenditures, etc. Usually, the model structure was fairly simple, following the main structure of the national model. These models have mainly been used to provide regional forecasts of a limited number of economic indicators (pp. 258-9).

2.2 A One-Sector, One-Region Model

Intriligator [1971] presents the single-region neoclassical model of optimal growth as follows: total regional output (Y(t)) is either consumed or invested. Denoting consumption at time t as C(t) and investment as I(t), the region's income identity is written as

$$Y(t) = C(t) + I(t). \tag{2.1}$$

Investment is used both to augment capital stock and to replace depreciated capital. If K(t) denotes capital stock at time t, capital accumulation is defined as the time rate of change of the capital stock, dK/dt. Assuming a constant proportionate rate of depreciation μ, the gross investment identity may be written as

$$I(t) = dK/dt + \mu K(t). \tag{2.2}$$

Aggregate output is a function of aggregate labor (L) and capital (K) inputs, and the relationship is given by the production function

$$Y = F(K, L). \tag{2.3}$$

Assuming that the production function exhibits constant returns to scale implies that, for any positive scale factor α,

$$F(\alpha K, \alpha L) = \alpha F(K, L) = \alpha Y. \tag{2.4}$$

In particular, if $\alpha = 1/L$:

$$\frac{Y}{L} = F\left(\frac{K}{L}, 1\right) = f\left(\frac{K}{L}\right), \tag{2.5}$$

where the function f(.) gives output per worker as a function of capital per worker. Denoting per-worker quantities by lower-case letters, (2.5) may be rewritten as

$$y = f(k), \text{ where} \tag{2.6}$$

$$y(t) = \frac{Y(t)}{L(t)}, \quad k(t) = \frac{K(t)}{L(t)}. \tag{2.7}$$

Similarly denoting consumption per worker and investment per worker by the lower-case letters c(t) and i(t), respectively, the income identity (2.1) may be rewritten as

$$y(t) = c(t) + i(t), \tag{2.8}$$

and the gross investment identity (2.2) as

$$i(t) = \frac{dK/dt}{L(t)} + \mu k(t). \tag{2.9}$$

Using the result

$$dk/dt = \frac{d}{dt}\left(\frac{K}{L}\right) = \frac{dK/dt}{L} - k\frac{dL/dt}{L}, \tag{2.10}$$

(2.9) may be rewritten as

$$i(t) = dk/dt + \left(\mu + \frac{dL/dt}{L}\right)k. \tag{2.11}$$

If the labor force is assumed to grow at a given exponential rate n so that

$$\frac{dL/dt}{L} = n, \tag{2.12}$$

the gross investment identity (2.11) becomes

$$i(t) = dk/dt + (\mu + n)\,k = dk/dt + \lambda k, \tag{2.13}$$

where λ is defined as the sum of the depreciation rate and the labor force growth rate:

$$\lambda = \mu + n, \tag{2.14}$$

and is assumed to be a positive constant.

The three equations (2.6) (the production function), (2.8) (the income identity), and (2.13) (the gross investment identity) are then combined to yield the fundamental differential equation of neoclassical growth:

$$f(k(t)) = c(t) + \lambda k(t) + dk/dt, \tag{2.15}$$

which effectively allocates output per worker among three uses: consumption per worker, c; maintenance of the level of capital per worker, λk; and net increases in the level of capital per worker, k.

It is assumed that the government, acting as a central planner, wishes to maximize a collective utility function which depends positively on the level of consumption per worker, c(t). Denoting the utility function as

$$U = U(c(t)), \tag{2.16}$$

the objective functional may be written as

$$W = \int_{t_0}^{t_1} e^{-\delta(t-t_0)} U(c(t))\, dt, \tag{2.17}$$

representing the discounted value of the utility stream accruing over the planning horizon $[t_0, t_1]$. The rate of discount, δ, is the marginal rate of substitution between present and future utility. The government must find a time path for the only control variable, consumption per worker, c(t), so as to maximize the objective functional (2.17), subject to the equation of motion (2.15) corresponding to the only state variable, k(t), the level of capital per worker (Intriligator [1971], pp. 399-402, 405-7).

2.3 A One-Sector, Two-Region Model

Intriligator [1964] presents a two-region setting wherein each region has a Harrod-Domar production function with a constant capital-output ratio:

$$Y_j = b_j K_j, \quad j = 1, 2, \text{ where} \tag{2.18}$$

Y_j is the level of output, K_j is the capital stock, and $1/b_j$ is a fixed requirement of capital per unit of output, in region j. If the constant savings ratio in region j is s_j, the total funds available for investment are

$$s_1 Y_1 + s_2 Y_2 = g_1 K_1 + g_2 K_2, \tag{2.19}$$

where $g_j = s_j b_j$, $j = 1, 2$. Ignoring depreciation, and letting β be the proportion of investment funds allocated to region 1, the two regional net (and gross) investment identities are given by the differential equations

$$\frac{dK_1}{dt} = \beta (g_1 K_1 + g_2 K_2), \text{ and} \tag{2.20}$$

$$\frac{dK_2}{dt} = (1-\beta) (g_1 K_1 + g_2 K_2). \tag{2.21}$$

Total population, P, is normalized to 1 at the beginning of the planning period, and is assumed to grow at a given exponential rate n, so that

$$P(t) = e^{nt}. \tag{2.22}$$

The objective functional represents the value of the undiscounted stream of per capita consumption summed over the two regions, and is shown as

$$W = \int_0^T e^{-nt} [(1-s_1) b_1 K_1 + (1-s_2) b_2 K_2] \, dt. \tag{2.23}$$

The government, acting as a central planner, must find the time path for the allocation proportion $\beta(t)$ (the only control variable) that maximizes the welfare functional (2.23) subject to the equations of motion (2.20) and (2.21) corresponding to the two state variables $K_j(t)$, $j = 1, 2$ (the levels of regional capital stock) (Intriligator [1964], pp. 659, 661-2).

2.4 A One-Sector, Two-Region Model With a Public Sector

Extending the above two-region model by introducing a public sector, Friesz[2] grapples with the allocation of a public investment fund between two regions, so as to maximize the discounted stream of national income over a specified planning horizon:

$$\text{Max } J = \int_0^T e^{-\rho t}[x_1(t) + x_2(t)]\,dt \tag{2.24}$$

where x_1 and x_2 are the respective regional income levels. Private investment and the generation of income are held exogenous, though it is conceded that "these processes are assumed to occur simultaneously with the allocation process" (pp. 72-74).

Production is defined as a Harrod-Domar process, which assumes a fixed capital-output ratio. Each region has an initial level of private investment, which translates into output or income growth through an exogenous, region-specific output-capital ratio for the private sector:

$$x_i(t) = \sigma_i K_i(t) \text{ and } x_i^0(t) = \sigma_i K_i^0(t) = \sigma_i I_i(t) \text{ for } i = 1,2. \tag{2.25}$$

A given, region-specific savings ratio for the private sector translates regional income into gross savings available for private investment:

$$s_i(t) = v_i x_i(t) \text{ for } i = 1,2. \tag{2.26}$$

Private savings are taxed at an endogenously determined rate r(t) that is common to the two regions. Allowing for tax payments and summing over the two regions yields total net private savings available for private investment:

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[2] Wu presents a systematic review of this and several other extensions of the two-region model.

$$I(t) = \sum_{i=1}^{2} v_i(1-r(t))x_i(t) = \text{total private investment.} \qquad (2.27)$$

This, in turn, determines output or income generation in the private sector. Given, region-specific savings ratios for the public sector are applied to regional tax revenues to yield regional public savings. Summing over the two regions then gives the total public investment fund:

$$P(t) = \sum_{i=1}^{2} u_i r(t) x_i(t) = \text{total public investment fund,} \qquad (2.28)$$

where u_i is a given public sector savings ratio for region i.

Given, region-specific output-capital ratios for the public sector translate public investment into public-sector output or income growth. Total private and total public investment are allocated between the two regions in constant (given) proportions:

$$I_1(t) = \lambda \left(\sum_{i=1}^{2} v_i(1-r(t))x_i(t) \right) \text{ and} \qquad (2.29)$$

$$I_2(t) = (1-\lambda) \left(\sum_{i=1}^{2} v_i(1-r(t))x_i(t) \right), \qquad (2.30)$$

where λ is the private investment share of region 1 (given);

$$P_1(t) = \nu \left(\sum_{i=1}^{2} u_i r(t) x_i(t) \right) \text{ and} \qquad (2.31)$$

$$P_2(t) = (1-\nu) \left(\sum_{i=1}^{2} u_i r(t) x_i(t) \right), \qquad (2.32)$$

where ν is the public investment share of region 1 (given).

Total income growth in each region is then the sum of its shares of private and public sector output. Friesz's growth equations may be written as

$$x_i^0(t) = \sigma_i I_i(t) + \delta_i P_i(t) \text{ for } i = 1, 2 \qquad (2.33)$$

where σ_i and δ_i are given private and public output-capital ratios.

The model is solved for the optimal tax rate r(t) so as to maximize the objective functional (2.24) subject to the equations of motion (2.33) of the two state variables $x_i(t)$, which denote the regional income levels (Friesz, pp. 72-77).

Friesz then attempts to extend the basic model to address multiple objectives with region-specific Cobb-Douglas production functions. The objective functional is transformed into a linear combination of the several objectives using exogenous weights to reflect political priorities. Finally, Friesz expands the model to include exhaustible natural resources and technological progress (p. 159).

Friesz sets out to determine the optimal time path for the interregional allocation of public investment between the two regions, but goes on to impose given proportions on the two regions. His effective control variable, the common tax rate, actually deals with the optimal combination of total public and private investment. The idea of applying savings ratios to public-sector income probably allows for leakages or unproductive expenditures. The direct involvement of the public sector in productive activity may be justified at the national level; at the regional level, however, public investments may more aptly play only a facilitating role in private-sector activity--apart from providing a minimum level of social services. The formulation of a multiple-objective model with multiple constraints is instructive. Overall, the model is of limited use in a substate or even a subnational context, for there are no interregional

flows responding to policy changes. The importance of interregional linkages is underscored by Nijkamp et al.:

> It is evident that interactions among regions should be properly represented in applied multiregional economic models. This goes without saying for models at national-regional planning and policy levels. The treatment of such interactions is less obvious, but still warranted for cases where one region is in the focus of the analysis and the others serve as composite system exteriors (p. 260).

With reference to the aggregative nature of most optimal control models of regional growth, Wu notes that,

> in particular, regional production functions are likely to be different among regions. It should also be observed that economic structure varies among regions. Most often the productivity of certain sectors, e.g., the agricultural sector, in a region is in a decreasing returns phase, while other sectors, e.g., the service sector, may be in an increasing returns phase. Therefore, a regional aggregate production function, in a sense, is inappropriate, and a regional multisector production function is thus required in our control models. Unfortunately this sort of model has not yet been successfully formulated (p. 55).

In this context, Wu documents the two-region model in Czamanski [1982], where two industrial sectors are specified for each region: a traditional sector defined by a Leontief production function with capital as a binding constraint, and a progressive sector with a homogeneous nonlinear production function. The model assumes complete malleability of capital between the sectors (Wu, pp. 88-91).

Like Friesz, all the models reviewed by Wu pertain to a central government allocating resources between regions. As such, they are not directly applicable to a local government allocating resources among different uses in a single region. Nevertheless, Wu does recognize some important considerations that should go into modelling regional structure (region-specific, multisector production functions) and interregional relationships (labor migration, p. 64, and capital flows, p. 90). Wu also presents an application of a nonlinear programming approach to solving a complex multiobjective control model with its several ramifications (pp. 121-164).

2.5 A Multiregional, Disaggregated Model

Chatterji [1983] uses an optimal control approach to study the relationship between pollution control and national welfare in a multiregional framework. Though the model does not fall directly within the genre of regional growth models, it is pertinent to the present context for two reasons: (i) pollution control is said to compromise economic growth, and (ii) a relatively detailed system of interregional relationships forms the core of the model. Every region is characterized by three sectors: locally or regionally consumed goods, nationally consumed goods, and pollution abatement goods. Locally consumed goods are fully produced within the region; production of nationally consumed goods is distributed over the several regions in the country; pollution abatement is meant to combat pollution generated by regional production in all three sectors. By diverting investment and causing unemployment, abatement compromises the level of economic activity in the region. At the same time, it has a positive effect on regional welfare. This is the essence of the tradeoff to be addressed by policy. Every region has a welfare function influenced by the regional pollution level, the regional unemployment rate, the final demand for local and for national goods, and the pollution tolerance level (the negative final demand for pollution). Regional welfare functions are assumed simply to sum to a national welfare function. This, then, is the objective functional to be maximized over some planning horizon (pp. 129-30):

$$\text{Max}_C\ W_T = \int_{t_0}^{t_1} \Big[\sum_{j=1}^{U} W_j(R_j, u_j, Y_{jR}, Y_{jT}, Y_N) \Big] dt \qquad (2.34)$$

where W_T is the national welfare function, W_j the welfare function of region j, R_j the pollution level in region j, u_j the unemployment level in region j, Y_{jR} the final demand for local goods in region j, Y_N the

(national) final demand for national goods, and Y_{jT} the pollution tolerance level in region j.

The control variables are the final demand for regional goods, pollution norms (negative final demand for pollution) and national goods. State variables are distinguished as stock and flow variables--the former include regional population, pollution level and unemployment; the latter include the production levels of regional, national and anti-pollution goods (p. 128). Besides the growth equations, there are also some systemic constraints in the model. The model is logically divided into four blocks: production, demographic, pollution, and unemployment.

The production block relies on given and static input-output and capital coefficients matrices to specify the linkages among the three sectors in the region. Sectoral production levels are thus simultaneously determined as the sum of derived demand for the intermediate and investment goods of the sector and final demand in the sector. For simplicity, every sector is assumed to produce a single commodity, and regional final demand for national goods is taken to be a fixed fraction of total national demand. Interestingly, the production of capital goods in any sector is implicitly treated as the rate of change of total production in the sector, over time. This greatly simplifies the derivation of the growth equations (pp. 122-125):

$$X_{jN} = a_{jNR}X_{jR} + a_{jNT}X_{jT} + a_{jNN}X_{jN} + b_{jNR}X^{0}_{jR} + b_{jNT}X^{0}_{jT} + b_{jNN}X^{0}_{jN} + Y_{jN}, \qquad (2.35)$$

$$X_{jR} = a_{jRR}X_{jR} + a_{jRN}X_{jN} + a_{jRT}X_{jT} + b_{jRR}X^{0}_{jR} + b_{jRN}X^{0}_{jN} + b_{jRT}X^{0}_{jT} + Y_{jR}, \text{ and} \qquad (2.36)$$

$$X_{jT} = a_{jTR}X_{jR} + a_{jTT}X_{jT} + a_{jTN}X_{jN} + b_{jTR}X^{0}_{jR} + b_{jTT}X^{0}_{jT} + b_{jTN}X^{0}_{jN} + Y_{jT} \qquad (2.37)$$

where X_{ji} is the production level in sector i of region j, X_{ji}^0 the production level of capital goods in sector i of region j, $A_j = \{a_{jpq}\}$ a given input-output matrix for region j, $B_j = \{b_{jpq}\}$ a given capital coefficients matrix for region j, $Y_{jN} = L_j Y_N$, where L_j is given, and $\Sigma_j L_j = 1$.

The demographic block ignores the age-sex structure of the population. Changes in regional population over time result from a given rate of natural increase and total net migration into the region from all other regions. Net migration between any two regions is modelled as a function of the relative unemployment rate, the relative production of national goods, the relative population, and the "economic distance" between them (pp. 126, 132). The interregional migration equations are assumed to be estimated exogenously. The population growth identity is written as

$$P^0 = B - D + M \tag{2.38}$$

where P^0 is the population growth rate, B and D are given birth and death rates, and M is an endogenous rate of migration given by

$$M_j = \sum_i M_{ij} \text{ where i is not equal to j, and} \tag{2.39}$$

$$M_{ij} = \beta_0 + \beta_1 u_i + \beta_2 u_j + \beta_3 X_{iN} + \beta_4 X_{jN} + \beta_5 P_i + \beta_6 P_j + \beta_7 d_{ij} \tag{2.40}$$

where M_{ij} is the net migration between regions i and j, u_i and u_j are the respective unemployment levels, X_{iN} and X_{jN} the respective production levels of national goods, P_i and P_j the respective population levels, and d_{ij} is the "economic distance" between regions i and j.

The pollution block assumes full abatement, and defines the output of the abatement sector as the total pollution generated by the regional and national goods sectors--i.e., by both their intermediate/final and capital goods subsectors--less a tolerance level (negative final demand).

Unit emissions in any sector are measured by given pollution coefficients (p. 126).

The unemployment block defines labor supply with a given labor force participation rate, after allowing for structural unemployment. Regional employment is related positively to production in the regional and national goods sectors, and is related negatively to that in the abatement sector. The loss in total regional output resulting from abatement is taken as a fixed fraction of abatement-sector output. Thus, effective regional output is the sum of regional and national goods output, less the loss from abatement. An average labor intensity for the economy is then used to convert effective output into employment. Subtracting this from effective labor supply yields the unemployment level (p. 127). Thus,

$$u_j = (1-k)s_jP_j - \theta(X_{jR} + X_{jN} - \alpha_0 X_{jT}) \qquad (2.41)$$

where k is the structural unemployment rate, s_j the labor force participation rate, θ an average labor intensity for the economy, and α_0 the loss in regional output per unit of abatement output (given).

As an overall description of a multiregional economy, Chatterji's model is extremely insightful: it is generalizable to more than two regions; it has a disaggregated sectoral structure; it explicitly includes intersectoral materials linkages; and it allows dynamic adjustment of interregional migration flows in response to relative economic conditions. It is also unique in that policy is attempted at the local level.

On the negative side, the weakest link in the model is the fixed-proportions nature of regional production: capital and materials inputs are determined by static input-output coefficients, and labor inputs are determined by an average labor intensity. A fuller formulation would permit endogenous regional wage rate determination and changing capital-labor ratios in response to changing relative factor prices. In terms of intersectoral material inputs, Andersson and Kuenne [1986] present a

detailed scheme for devising dynamic input-output coefficients as cost-minimizing functions of all regional (material input) prices and inter-regional transportation costs (pp. 238-241). Admittedly, however, such a refinement is likely to entail considerable computational cost.

Chatterji's use of a prior distribution of national goods production would be particularly questionable in a context of changing relative factor prices across regions. In terms of model application, a single, composite measure of pollution must be difficult to define. So also, the use of final demand as a control variable in itself is not straightforward. Thus, the actual policy variables and their bearing on final demand must be made explicit. Lastly, the concept of a welfare function could prove elusive to policy-makers.

2.6 Closing Remarks

An ideal model of endogenous regional growth would replace the regulatory policy measure in Chatterji's model with a growth-inducing policy instrument, while otherwise building on its strengths. Just as the compromising effect of pollution control measures on regional activity is offset by their positive effect on regional welfare, so also, the negative effect of local taxes may be offset by facilitating public expenditures. These fiscal measures may be used to optimize a more readily conceivable objective, such as consumption or income per capita. Flexible production forms would permit factor substitution in response to changing relative factor prices; this would entail an endogenous mechanism for regional wage rate determination, as pointed out above. Lastly, changing relative factor prices across regions would induce endogenous interregional flows of both capital and labor.

The family of multiregional computable general equilibrium (CGE) models contain a relatively detailed treatment of regional structure and

interregional linkages[3]. However, even dynamic multiregional CGE models do not set out with an overt optimization criterion; rather, they only trace out equilibrium growth paths (Kraybill, p. 34). Thereby, such models focus on the effects of changes in policy variables on specific regional structures. In contrast, this study seeks to explore the relationship between optimal local policy and regional structure in general. To this end, Chapter 3 will present a conceptual layout that incorporates structural detail within an explicit policy framework.

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[3] For an excellent summary of the structural features of such models, see Kraybill [1992].

CHAPTER 3
ENDOGENOUS REGIONAL GROWTH: AN ANALYTICAL FRAMEWORK

3.1 Introduction

The growth models reviewed in the previous chapter focus on the interregional allocation of public investment by a central government, and are therefore particularly inappropriate in the context of endogenous regional development. Besides, they do not make a functional distinction between public and private investment. In their dynamic CGE model of the Indian economy, Becker et al. [1992] make the same observation about dynamic CGE models in general (p. 15). By assuming away several integral components of interregional activity, such as private capital formation, migration, and labor market responses, the growth models reviewed in Chapter 2 do not present the complete regional setting within which policy-makers must operate. In an attempt to address these concerns, this chapter will be used to develop an optimal control framework for a simplified two-region setting, wherein a local government seeks to foster economic growth by allocating its own funds among alternative developmental uses such as physical infrastructure and human capital investments. Such a disaggregated view of public expenditures may be contrasted with the monolithic view typical of earlier models. The framework will include multiple sectors, sector-specific production functions, and regional endowments of private capital, human capital and public infrastructure. It will endogenize the regional wage rate and product prices in locally-oriented sectors, and will include dynamic adjustments in migration and private investment flows. Whereas the treatment in this chapter will be largely relational and conceptual, a precise mathematical adaptation with specific functional forms will be presented in Chapter 4.

In spirit, the model may be seen as a theoretical common denominator of regional econometric models; the explicit policy orientation, however, places it in the realm of regional growth theory and of control theory applications to regional growth. The model is thus not a direct descendant of multiregional CGE models, although it bears a marked resemblance to that family in several key aspects. In what follows, therefore, references to CGE models are illustrative at best, and by no means exhaustive. As noted earlier, even dynamic CGE models do not incorporate an explicit optimization criterion. In attempting to identify optimal time paths for policy variables, the model developed here constitutes a distinct contribution to the CGE literature as well.

3.2 Model Overview

The model has two regions R and S with R being the region of policy interest. N is the union of R and S and represents the universe of the model. It is useful to think of R as a small region within a nation N, and of S as the rest of the nation. Region R has a local government that imposes a tax (a property tax, an income tax, or a sales tax) at an endogenously determined rate, and the local government uses the tax revenue to finance investments in physical infrastructure (roads, bridges, public transport, etc.) and human capital (schools, libraries, vocational training facilities, colleges, etc.). Exogenous grants and transfers from higher levels of government supply funds for basic social services such as fire protection, police protection, and garbage disposal. It is assumed for simplicity that such funds are adequate for the purpose, and consideration of such services is not explicitly treated in the conceptual model. The government must choose optimal time paths for the tax rate and the allocation ratio in the interest of a prespecified objective functional. Arguing that the favorable effects of public expenditures vary by expenditure type and across private investment sectors, the optimal allocation of

public funds may be expected to differ both across regions and over time for a given region.

The model has the following components: (a) an endogenous government block (local tax rate; current investment in and total stock of physical infrastructure; and current investment in and regional stock of human capital); (b) an exogenous government block (intergovernmental grants and transfers; supply of basic social services); (c) a private investment block (sectoral current investment and private capital stock); (d) a production block (sectoral production levels; price levels in locally-oriented sectors; domestic and export sales; gross and disposable regional income); (e) an employment block (sectoral and total employment levels; labor force participation rate; regional unemployment rate; regional wage rate); (f) an exogenous prices block for export-led sectors; and (g) a population block (given birth and death rates and net migration).

The dynamic interrelationships among the different components of the model may best be described with reference to the accompanying flowcharts (Figures 1 and 2). The local government uses its tax revenues to bolster regional stocks of physical infrastructure and human capital, thereby increasing the region's potential output through an outward shift in its product supply curves. Enhanced export competitiveness induces private investment in export-led sectors and adds to sectoral private capital stocks. An outward shift in sectoral labor demand curves increases sectoral employment and the regional wage rate. Increased export production boosts gross regional income, which induces domestic demand in locally-oriented sectors and so feeds back into the growth process. In the labor market, a lower unemployment rate and a higher wage rate increase local labor force participation and net migration into the region. This built-in labor supply response tempers the growth process in a lagged fashion and serves as an important dynamic adjustment mechanism. Growth in regional activity provides a wider tax base for the local government (through increased private capital stocks in the case of a property tax

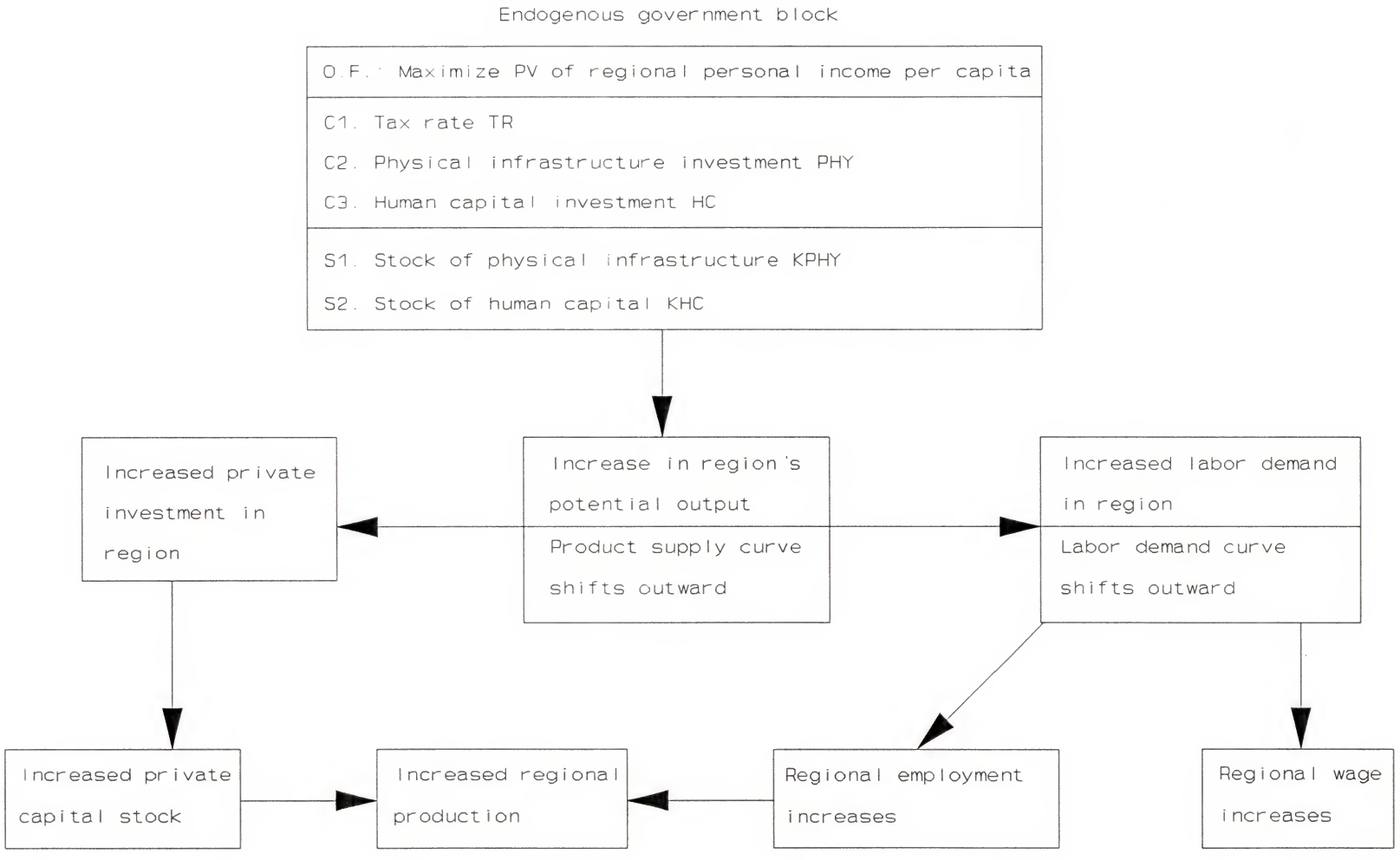
Endogenous government block
O.F.: Maximize PV of regional personal income per capita
C1. Tax rate TR
C2. Physical infrastructure investment PHY
C3. Human capital investment HC
S1. Stock of physical infrastructure KPHY
S2. Stock of human capital KHC
Increased private investment in region
Increase in region's potential output
Product supply curve shifts outward
Increased labor demand in region
Labor demand curve shifts outward
Increased private capital stock
Increased regional production
Regional employment increases
Regional wage increases

Figure 1 Endogenous Regional Growth: A Schematic Framework

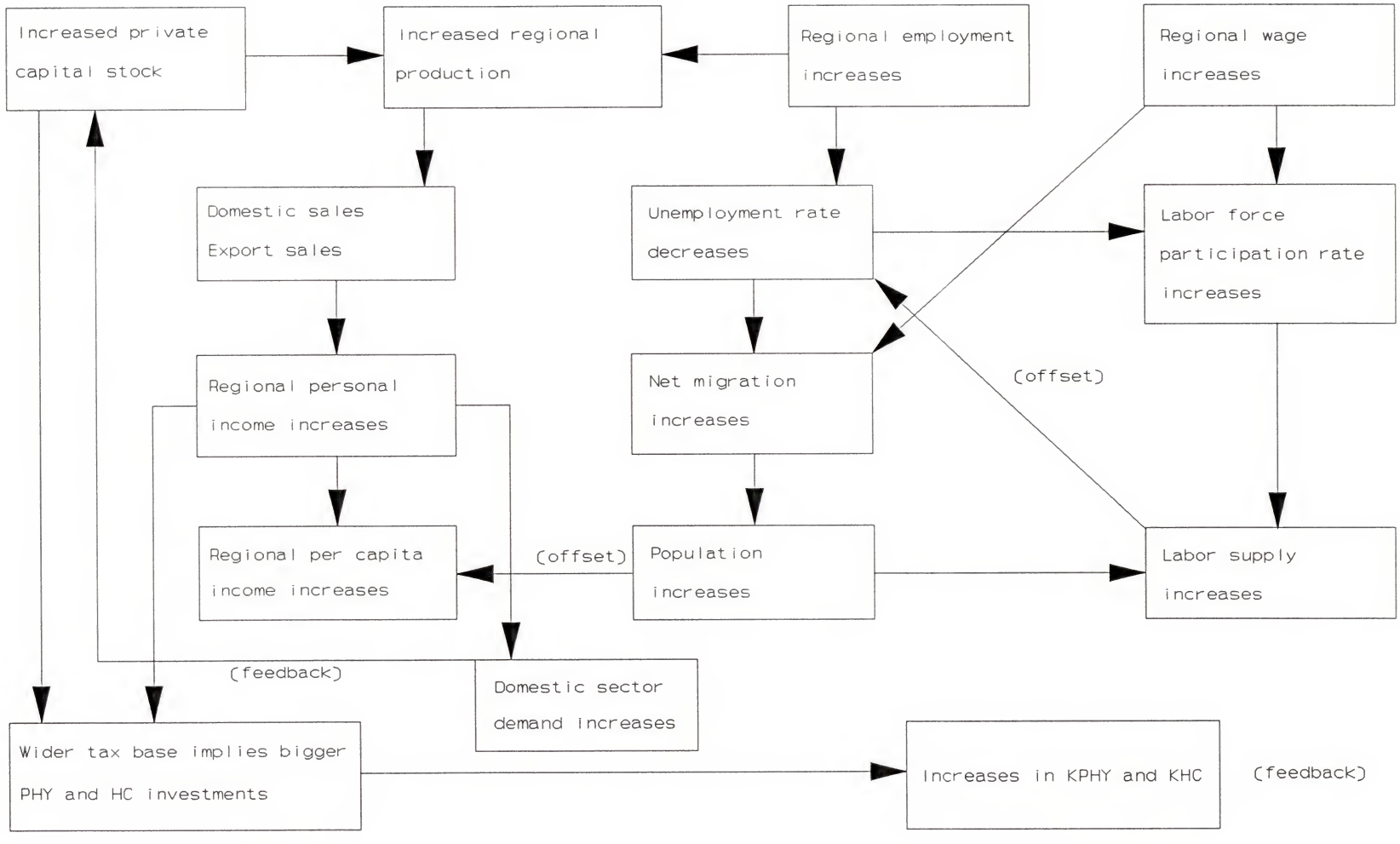

Figure 2 Endogenous Regional Growth: A Schematic Framework (2)

and through increased regional income in the case of an income tax). Bigger current investments in and growing stocks of physical infrastructure and human capital feed back into the economy, making regional growth an endogenous and cumulative process. The critical underlying argument is that public investments confer long-term productivity advantages which more than offset the short-term compromise posed by the local tax. Empirical validation for this assertion may be found in Helms' [1985] analysis of real personal income growth in 48 states of the U.S. during 1965-79 (p. 574).

3.3 The Objective Functional

As already noted, Friesz lists seven different objectives that might guide regional public investment: (i) consumption, (ii) time-stream of income, (iii) end-of-period income, (iv) income growth rates, (v) acceleration of income growth rates, (vi) interregional equity, and (vii) wages (pp. 123-25). Chatterji uses a regional welfare function (pp. 129-30). For present purposes, it is assumed for simplicity that the government wishes to maximize the discounted present value of per capita personal income in the region. Conceding the difficulties involved in measuring changes in total regional welfare, Haveman [1976] suggests that per capita gross regional product or per capita income might serve as "empirically accessible indicators" that, though not complete, are significantly correlated with real economic welfare (p. 450). Coffey and Polese [1984] define development as "sustained and irreversible economic growth which will be characterized, in quantifiable terms, by an increase in real income per capita for a given region" (pp. 1-2); they recognize, however, that "the process of development will necessarily be accompanied by certain structural and social transformations" (p. 2). Ignoring the latter and focusing only on per capita income, the objective functional may be written as

$$\text{Max}_{C^R(t)} \quad J = \int_0^{\infty} e^{-rt} YDPC^R(t)\, dt \tag{3.1}$$

where $C^R(t) = (TR^R(t), PHY^R(t), HC^R(t))$ is the control vector, $TR^R(t)$ is the endogenous tax rate, $PHY^R(t)$ is current public investment in physical infrastructure, $HC^R(t)$ is current public investment in human capital, $YDPC^R(t)$ is the disposable personal income, per capita, in region R, and r is a given rate of discount.

3.4 Private Investment

The entire private sector may be illustratively divided into three subsectors: (i) extractive and other natural resource-based industries (agriculture; forestry, fisheries and minerals; power and energy; and tourism and recreation) that can supply local or export markets; (ii) manufacturing industries (intermediate goods; finished goods) that can supply local or export markets; (iii) services and other industries (construction; transportation; communications; retail trade; finance, insurance and real estate; personal and business services; and health, education and cultural services) that are largely shaped by local demand but can supply export markets as well.

Private capital is assumed to be homogeneous, and perfectly mobile between regions and across sectors. The existence of national capital markets ensures uniform nominal cost of capital across regions. While nominal rates of return may be assumed uniform, effective expected rates of return can vary between regions to reflect different risk levels. Product prices in the export-led industries (natural resource-based and manufacturing sectors) are assumed exogenous to the model; in the case of the services sector, however, where the local demand component assumes greater relative importance, a suitable local demand function must be specified to permit the endogenous determination of both output and price.

Regional investment in each sector is taken to depend upon an exogenously determined national investment level in that sector. National sectoral levels may be assumed responsive to relative price changes as between sectors. The appropriate concern, then, is with the distribution of such investment among regions.

In the natural resource-based industries, the region's initial capital stock in the sector is assumed to reflect the availability (or lack) of natural resources. For the most part, therefore, new investment in this sector is constrained by the existing distribution of capital stock. Choice between similarly endowed regions is influenced by the control vector C and relative wage levels across regions. Thus, new investment in natural resource-based industries in period t, $I_1^R(t)$, is

$$I_1^R(t) = I_1^R\left(I_1^N(t), K_1^R(t), C^R(t), \frac{W^R}{W^N}(t)\right) \tag{3.2}$$

where the arguments represent, respectively, the national investment level in the sector, the region's capital stock in the sector, the regional control vector, and the regional wage rate relative to the national.

Intermediate manufacturing investment is shaped to a significant extent by the region's existing capital stock in finished-goods manufacturing, as this reflects the size of the local market. Investment in the export-led production of intermediate goods, and in finished-goods manufacturing at large, is shaped by the control vector C and the relative regional-national wage rate. Thus, new manufacturing investment, $I_2^R(t)$, is given by

$$I_2^R(t) = I_2^R\left(I_2^N(t), K_2^R(t), C^R(t), \frac{W^R}{W^N}(t)\right) \tag{3.3}$$

where the arguments are defined as before.

Local demand for the output of the services and other industries originates from all three sectors on the production side, and from the population in general, on the consumer side. Local demand proxies would thus be the total private capital stock and regional population. Competitive exports are, as before, influenced by the control vector C and the relative regional-national wage rate. Thus, new investment in services and other industries is given by

$$I_3^R(t) = I_3^R\left(I_3^N(t), \sum_{i=1}^{3} K_i^R(t), C^R(t), \frac{W^R}{W^N}(t), POP^R(t)\right) \qquad (3.4)$$

where the second argument represents the region's total private capital stock and the fifth, the regional population.

A formulation broadly similar to those above may be found in Gertler's [1987] analysis of the spatial distribution of manufacturing investment among Canada's provinces during 1955-1983. Gertler argues that interregional variations in the cost of labor and the cost of or return to capital are important from a neoclassical point of view. The size of local demand and a region's access to national demand may be included as additional considerations. Existing capital stock and public infrastructure would reflect positive agglomeration economies (pp. 28-30, 35).

Total private capital stock in any sector, $K_i^R(t)$, is given by the identity

$$K_i^R(t) = K_i^R(0) + \int_0^t I_i^R(t)\,dt - \int_0^t D_i . K_i^R(t)\,dt \text{ for i} = 1, 2, 3 \qquad (3.5)$$

where D_i is a given, sector-specific rate of depreciation.

3.5 Interaction between Physical Infrastructure and Output

Production in any sector may be cast as a function of private capital stock and labor. At the regional level, public infrastructure has

typically been included as an additional factor in a flexible production function (Mera; Costa et al. [1987]). In a review article on the relationship between infrastructure and economic growth, Munnell [1992] confirms the popularity of this approach in empirical studies at all levels of government--national, state and local. Almost without exception, all these studies report significant positive effects of infrastructure on economic growth; the magnitude of the effect is comparable across studies at a given level of government, but decreases as the area of focus shrinks from nation to state to metropolitan area, possibly because of leakages. Nonetheless, these findings are criticized on three counts: (i) that common trends in output and infrastructure data could lead to spurious correlations; (b) that the actual causation may run from output to infrastructure rather than the other way about; and (iii) that a cost function framework may be preferable to production function estimation, since it would include input prices and disentangle the effects of infrastructure, scale economies, and fixed effects on production costs (Munnell, pp. 191-195).

In order to prevent the potential substitutability of public capital for other factors (labor and private capital) that the conventional approach allows, an alternative formulation is advanced here: whereas private capital and labor are substitutable inputs in each sector, public infrastructure is akin to a fixed-proportions input. The basic idea may be found in Schroeter and Azzam's [1991] time-series analysis of marketing margins in the U.S. hog-packing industry. Their specification of the industry-level marginal processing cost function embodies a processing technology with three inputs: labor, energy, and transportation services; input substitution is possible between labor and energy only, so that transportation services essentially enter in fixed proportions (pp. 994-5). Such a formulation stresses both the distinction between public and private capital and the complementary nature of public capital. In

effect, it allows public infrastructure to serve as a constraint on the size of the regional economy.

A third possible approach would be to embody the enhancing effects of public capital in the private capital stock in each sector. Then, actual private capital stock would be scaled upwards exponentially in the production function, to yield an effective capital stock. By construction, the effects may be allowed to differ across sectors. This may be shown as

$$q_i^R(t) = q_i^R\left(K_i^R(t).e^{\alpha_i^R(t)}, N_i^R(t)\right) \text{ for } i = 1,2,3 \qquad (3.6)$$

where $q_i^R(t)$ is the level of production in sector i, $N_i^R(t)$ is the employment level in sector i, and the scaling factor

$$\alpha_i^R(t) = \alpha_i^R(KPHY(t), t) \text{ for } i = 1,2,3 \qquad (3.7)$$

converts actual capital stock, $K_i^R(t)$, into effective capital stock. The idea that public infrastructure may, in fact, work *through* private capital and labor is hinted at by Coffey and Polese [1984]:

> rather, per capita income growth remains largely unexplained in the form of a residual factor which is often interpreted as a reflection of "the progress of knowledge", which in turn is partially embodied in the population (and partially in capital) (p. 4).

The distinction between actual and effective inputs via exponential productivity effects is after Smith [1972] (p. 37).

The ongoing nature of the controversy over physical infrastructure is reflected in Munnell's closing comment: "In summary, the critics are correct that the numbers emerging from the aggregate time series studies are not credible, and that more evidence is needed on the causation issue" (p. 195). The need to experiment with alternative formulations is therefore in order.

3.6 Interaction between Human Capital Investment and Output

The possible links between human capital investment and development are even less straightforward. Salamon [1991] identifies five dimensions to human capital investment: (i) elementary and secondary education; (ii) higher education; (iii) research and development; (iv) employment and training; and (v) supportive services (health care, nutrition, social services, and day care). Superficially, they may all be considered as additions to the region's human capital stock; however, there are important qualitative differences among them that cannot be captured in the context of a single aggregate labor input. A preliminary differentiation of labor into two types--unskilled and skilled--permits a better understanding of these differences.

Elementary and secondary education, along with supportive services, may be seen as a general qualitative improvement in a region's unskilled labor force, and as a prerequisite for proper use of the other three components. In the context of a production function, these investments are best modelled as unskilled labor-augmenting measures, since they "deepen" a region's unskilled labor endowment without a physical increase in the unskilled population. The essential nature of these investments is confirmed by empirical studies reported in Tallman and Wang's review article [1992a]. Using a cross-sectional sample of developed, developing, and less-developed countries, Psacharopoulos [1984, 1985] concludes that the returns to investments in primary education are greater than those to secondary and higher education (Tallman and Wang [1992a], p. 5). Easterlin [1981] examines a cross-section of countries to conclude that long-run economic development based on the growth of science and technology (the "research and development" component above) is conditional on widespread basic education (Tallman and Wang [1992a], p. 5). In another cross-sectional study of countries, Azariadis and Drazen [1990] use a literacy rate of 40% as an initial threshold level of human capital beyond which a country may experience accelerating growth. They report a positive

relationship between literacy and output growth (Tallman and Wang [1992a], p. 8). In the context of regional development, it is presumably in the sense of basic education that Hansen [1965] and Coffey and Polese [1984] recommend greater initial emphasis on human capital investments relative to infrastructural investments.

As the next link in the chain, higher education may be said to transform unskilled into skilled labor, albeit with significant lags. Thereby, this component actually increases the physical size of the skilled population relative to the unskilled population. Beyond this direct supply effect, however, higher education is also likely to have positive external effects on both unskilled and skilled labor generally. In terms of a production function with two types of labor, these external effects may be seen as skilled and unskilled labor-augmenting, since they "deepen" a region's skilled and unskilled labor endowments alike. In an empirical study of Taiwan, Tallman and Wang [1992b] use this idea with a single labor input. They create an aggregate human capital measure by weighting levels of education completed; this measure is then applied to actual labor input to form an effective labor input (Tallman and Wang [1992a], p. 9).

Investment in research and development is the crucial link that relates educational investments to rapid economic progress by fostering the application of skills and knowledge inculcated under the other components. Product and process innovations demand quality inputs from the higher education component, while the successful implementation of such innovations calls for both basic education and vocational and on-the-job training facilities. Modelling the exact relationship between research and development investments and production is a moot issue; however, the general tendency in the literature seems to be in favor of a private capital-augmenting construct. For example, Salamon suggests that investments in scientific research will be productive only if they translate eventually into specific industrial applications (p. 25). Romer [1990] provides

for human capital accumulation but sees its exploitation as the key to growth and development. Inasmuch as this exploitation leads to new and better capital goods, it is not human capital, *per se*, but human capital embodied in physical capital that makes for progress (Tallman and Wang [1992a], pp. 7-8, 9).

The employment and training component represents skill upgrading in a specific, work-related sense. It may be defined as a transformation of unskilled into skilled workers, supplementing the broader and slower component of formal higher education. Becker et al. use two labor markets segmented by skill, with an endogenous wage rate in each (p. 16). As one of several ways of generating labor productivity growth, they allow exogenous transformation of a share of the unskilled labor force into skilled workers each year (pp. 18-19).

Tallman and Wang [1992a] conclude their review on the following note: "It appears that in the literature on endogenous growth models theory may be ahead of the measurement. . . . Improvements in formulating human capital measures may establish a stronger link between human capital and growth" (pp. 9-10).

3.7 Labor Demand and the Wage Rate

Assuming that each sector is individually a price-taker in the labor market, sectoral employment levels, $N_i^R(t)$, may be calculated as profit-maximizing derived demands at given levels of private capital stock:

$$N_i^R(t) = N_i^R\left(q_i^R(t), K_i^R(t), W^R(t)\right) \text{ for } i = 1, 2, 3. \tag{3.8}$$

For a similar approach in the context of regional econometric modelling, see Taylor [1982] (p. 431).

The regional wage rate, $W^R(t)$, may be taken to vary directly with the national wage rate, $W^N(t)$, and inversely with the relative regional-national unemployment rate, $U^R(t)/U^N(t)$ (Taylor [1982], p. 432). Thus,

$$W^R(t) = W^R\left(W^N(t), \frac{U^R}{U^N}(t)\right). \tag{3.9}$$

3.8 Labor Supply

Population change in the region comes from natural increase (at a given rate) and net migration into the region. Net migration, $NM^R(t)$, may be taken to vary directly with the relative regional-national wage rate, $W^R(t)/W^N(t)$, and inversely with the relative regional-national unemployment rate, $U^R(t)/U^N(t)$. Non-economic incentives to migration are omitted for simplicity. Thus, regional population, $POP^R(t)$, is given by the identity

$$POP^R(t) = POP^R(0) + \int_0^t NM^R(t)\,dt + \int_0^t NI.POP^R(t)\,dt \tag{3.10}$$

where NI is a given rate of natural increase; net migration into the region, $NM^R(t)$, is given by the equation

$$NM^R(t) = NM^R\left(\frac{W^R}{W^N}(t), \frac{U^R}{U^N}(t)\right). \tag{3.11}$$

Before establishing a precedent for the admittedly oversimplified formulation of net migration, several nuances of interregional migration deserve mention. Inmigration and outmigration may need to be modelled separately, given that they are driven either by different factors or in differing degrees by the same factors (Menchik [1980], p. 197; Petto and Bender [1974], p. 10). Kahley [1991] observes that the factors determining the two aspects are not symmetric (pp. 17, 19). Greenwood [1985] stresses the importance of the distinction in estimating the effects of migration on regional structure (per capita income level, human capital stock) (p. 526). Further, personal characteristics of would-be migrants

are at least as important as place characteristics. The former include employment status, marital status, family composition, age, sex, health, education level, and migration history; the latter include relative labor market and non-labor market attributes of regions (land and housing market conditions, state & local taxes, supply of public goods and environmental amenities) (Greenwood, p. 527). Thus, an unemployed person is more likely to respond to transitory changes in relative labor-market conditions, such as new job formation and unemployment rate (Greenwood, p. 532). For employed people, however, life-cycle considerations become more important--age, long-term employment mobility, employment status of the spouse, educational needs of children, health-related facilities, retirement options and environmental amenities make the migration decision a very circumspect one (Greenwood, p. 529). Kahley concludes that personal characteristics may explain outmigration better than inmigration, and place characteristics, inmigration better than outmigration (p. 14). Greenwood et al. [1986] suggest that migration represents a human capital loss to the origin (p. 232); this may be true of an employed migrant, but not necessarily so in the case of an unemployed migrant. The impact on the receiving region would seem to be ambiguous in either case.

In general, repeat migration is more likely than first-time migration. As a result, a region with a high rate of inmigration may also exhibit a high rate of outmigration, though with a lagged relationship between the two (Menchik, p. 197; Greenwood, pp. 532, 535). To the extent that previous migration from one region to another lowers information costs for potential migrants, a "bandwagon effect" may be created, making such migration cumulative. Among those who have already moved, intimate knowledge of the home region ("location-specific capital") favors return migration over nonreturn or onward migration. Coupled with the bandwagon effect, this could lead to strong bilateral flows between pairs of regions--an especially important consideration in a multiregional modelling context (Menchik, pp. 195-6; Greenwood, p. 535).

Ledent [1983] models both inmigration and outmigration as functions of relative economic conditions, with emphasis on own and other wage rates and unemployment rates. He converts a multiregional model into a two-region one by using weighted averages of those variables across all regions other than each origin region (Greenwood, p. 540). Milne [1981] has a similar framework, but uses wage rates, unemployment rates, and population density (Greenwood, p. 540). Taylor [1982] specifies the rate of net inmigration as a function of the relative regional-national aggregate real wage and unemployment rate (p. 430).

The region's labor force participation rate, $LFPR^R(t)$, may be seen as a function of the regional unemployment rate, $U^R(t)$, and the regional wage rate, $W^R(t)$. Abstracting from potential labor-leisure tradeoffs, the wage rate may be expected to have a positive effect on labor supply, on the grounds of increasing opportunity cost. For the same reason--and given the discouraged worker hypothesis--the unemployment rate may have a negative effect. Given the assumption that labor supply is not a binding constraint, the labor force participation rate merely helps to derive the regional unemployment rate by identity. The corresponding relationships are

$$LFPR^R(t) = LFPR^R(U^R(t), W^R(t)), \text{ and} \tag{3.12}$$

$$U^R(t) = \frac{1}{POP^R(t) \cdot LFPR^R(t)} \left[POP^R(t) \cdot LFPR^R(t) - \sum_{i=1}^{3} N_i^R(t) \right]. \tag{3.13}$$

3.9 The Public Sector

Changes in the region's stock of human capital, $KHC^R(t)$, result from public investment, $HC^R(t)$, and net migration, $NM^R(t)$. The effect of the former is assumed positive, and that of the latter, ambiguous. It is important to note that some scaling is involved in translating dollars of

expenditure and numbers of people into some quality or skill unit. The region's human capital stock is given by[1]

$$KHC^R(t) = KHC^R(0) + \int_0^t f_1(HC^R(t))\,dt + \int_0^t f_2(NM^R(t))\,dt. \qquad (3.14)$$

The difficulties involved in measuring the two integrals on the right-hand side of the above identity are compounded in the context of two kinds of labor. Firstly, the effect of human capital investment would vary by type of investment (basic education, higher education, and R & D), as noted in section (3.6) earlier. Secondly, regional human capital stock would need to be seen as some suitable aggregate of unskilled and skilled human capital stocks. Thirdly, migration flows of unskilled and skilled labor would need to be specified separately.

As in the case of private capital, public capital stock, $KPHY^R(t)$, is also subject to depreciation at a given, proportionate rate. It follows that

$$KPHY^R(t) = KPHY^R(0) + \int_0^t PHY^R(t)\,dt - \int_0^t D_{PHY}.KPHY^R(t)\,dt. \qquad (3.15)$$

As noted in Chapter 2 above, previous optimal control models of regional growth treat all public investment as physical capital investment. Besides, they assume such investment to be functionally identical to private investment; as a result, the public and private sectors in those models play competing roles in regional production. In this model, however, the public sector plays a supportive role inasmuch as public investments work through the production functions of the private sector.

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[1] For the need to distinguish between stocks and flows of human capital, see McNamara et al.

Moreover, there is a clear qualitative difference between the roles of physical and human capital investment.

3.10 Alternative Tax Measures

In its simplest form, gross regional personal income, $TPY^R(t)$, is defined as the sum of domestic and export sales in the three sectors, and is given by the identity

$$TPY^R(t) = \sum_{i=1}^{3} P_i^R S_i^R(t) + \sum_{i=1}^{3} P_i^S S_i^S(t) \qquad (3.16)$$

where the terms on the right-hand side denote domestic sales revenue and export sales revenue summed over the three sectors. A more complete formulation would account for commuter income flows, household transfer payments, and possible accrual of private capital income outside the region (Kraybill, pp. 17-18).

Tax payments to the local government are deducted from gross sales revenue to yield disposable regional personal income, $YD^R(t)$, which is divided by population to yield regional personal income per capita. In the case of a property tax, disposable income is given by

$$YD^R(t) = TPY^R(t) - \sum_{i=1}^{3} PTR^R(t).K_i^R(t), \qquad (3.17)$$

where PTR is the local property tax rate, and, in the case of an income tax, by

$$YD^R(t) = (1-ITR^R(t)).TPY^R(t), \qquad (3.18)$$

where ITR is the local income tax rate. Regional disposable personal income per capita, $YDPC^R(t)$, then becomes

$$YDPC^R(t) = \frac{YD^R}{POP^R}(t). \tag{3.19}$$

The local government's budget is assumed to balance on two counts--exogenous grants and transfers from higher levels of government are fully used up in the provision of basic social services, and local tax revenue goes entirely into investments in physical infrastructure and human capital. Thus, there is no provision for government debt. In the endogenous government block, therefore,

$$PHY^R(t) + HC^R(t) = \sum_{i=1}^{3} PTR^R(t).K_i^R(t) \tag{3.20}$$

in the case of a property tax; in the case of an income tax, the relevant budget constraint becomes

$$PHY^R(t) + HC^R(t) = ITR^R(t).TPY^R(t). \tag{3.21}$$

Finally, total sales in each sector must be limited by the production level, and the tax rate must be constrained to vary over the unit interval [0, 1]. These constraints are shown as

$$S_i^R(t) + S_i^S(t) \leq q_i^R(t) \text{ for } i = 1, 2, 3, \text{ and} \tag{3.22}$$

$$0 \leq PTR^R(t) \leq 1 \text{ or } 0 \leq ITR^R(t) \leq 1. \tag{3.23}$$

3.11 Closing Remarks

As a formal representation of endogenous regional growth, the schematic framework just presented is a distinct improvement over its predecessors. It casts the growth process explicitly within a local-level policy setting; it emphasizes alternative forms of public expenditures;

and, by incorporating multiple sectors, labor market responses, and dynamic adjustments in interregional migration and private investment flows, it provides a more detailed basis for regional policy analysis.

In order to probe the mathematical properties of the model and to establish its internal consistency, sensitivity analysis may be performed with respect to the following specific concerns: (a) whether the optimal time paths of the control variables do indeed vary by region; (b) whether differentiation of public investment by type is in fact superior to investment in either type alone; and (c) whether short-run slowdowns caused by local taxation are truly offset by long-run benefits from public investments. This would call for a precise mathematical rendition of the model with a fully specified objective functional, a specific local tax, specific functional forms for the various behavioral relationships, and chosen impact mechanisms for physical infrastructure and human capital investments. Such is the task for Chapter 4.

CHAPTER 4
AN OPERATIONAL MODEL

4.1 Background

The following section (4.2) will be used to present an illustrative mathematical model that falls entirely within the overall framework laid out in the previous chapter. Besides assuming particular functional forms for the several conceptual relationships, the model will have the following specific features: (i) it will be cast in discrete instead of continuous time, both to allow for lagged adjustments and to facilitate computation; (ii) by assumption, the local government will levy an income tax; (iii) the region of policy interest, R, will be characterized by two aggregate sectors, an export sector and a local sector--by obviating the need to distinguish between domestic and export sales in each sector, this assumption aids computation; (iv) product price will be exogenous in the export sector and endogenous in the local sector; (v) regional consumption will be explicitly introduced to permit endogenous determination of the local-sector price and a price deflator; (vi) physical infrastructure will be assumed to act as a constraint on regional production, rather than as a factor of production or as an embodied influence on private capital; (vii) there will be two kinds of labor, unskilled and skilled--this helps to distinguish between different kinds of human capital investment, as argued in Chapter 3; (viii) for computational reasons, human capital investment will be assumed to transform unskilled into skilled workers, instead of having embodied productivity effects on private capital or either labor input; and (ix) by assumption, the local government wishes to maximize real regional income, per capita.

4.2 A Mathematical Model

The model assumes two regions R and S with R being the region of policy interest, and S the rest of the world. Region R is a three-good economy in which two goods are produced--one an export good (X) and the other a locally consumed good (L)--and two goods consumed--the local consumer good (L) and an imported consumer good (M). Ignoring commuter incomes and household transfers, gross regional income is equal to total sales revenue which, by definition, includes profits and factor payments to private capital and labor. By assumption, all income is retained within the region. This is written as

$$Y_t = P_{Lt}Q_{Lt} + P_{Xt}Q_{Xt}, \tag{4.1}$$

where Y_t is gross regional income in period t, P_{Lt} the endogenous local good price, Q_{Lt} the production or sales of the local good, P_{Xt} the exogenous export good price, and Q_{Xt} the production or sales of the export good. Assuming that the local government levies a proportionate income tax at some given rate TR_t, regional disposable income is given by

$$Y_{dt} = (1-TR_t)\,(P_{Xt}Q_{Xt} + P_{Lt}Q_{Lt})\,. \tag{4.2}$$

Identical households seek to maximize Cobb-Douglas utility functions of the form

$$U = Q_m^{\sigma} Q_L^{(1-\sigma)},\ 0 < \sigma < 1,$$

where Q_m is total consumption of the import good, and Q_L the total consumption of the local good, subject to the budget constraint

$$P_mQ_m + P_LQ_L = Y_d.$$

The first-order conditions for utility maximization imply that

$P_m Q_m / Y_d = \sigma$, and $P_L Q_L / Y_d = (1-\sigma)$.

Substituting these expressions into the utility function gives the indirect utility function

$$U(Y_d, P_m, P_L) = \left(\frac{\sigma Y_d}{P_m}\right)^{\sigma}\left(\frac{(1-\sigma)\,Y_d}{P_L}\right)^{(1-\sigma)}, \text{ or}$$

$$U(Y_d, P_m, P_L) = Y_d\left(\frac{\sigma}{P_m}\right)^{\sigma}\left(\frac{(1-\sigma)}{P_L}\right)^{(1-\sigma)}.$$

A true multiplicative income deflator is then given by[1]

$$D_t = \left(\frac{\sigma}{P_{mt}}\right)^{\sigma}\left(\frac{(1-\sigma)}{P_{Lt}}\right)^{(1-\sigma)}. \tag{4.3}$$

Two types of labor--skilled and unskilled--are assumed (see Becker et al., p. 16). The government wishes to maximize the discounted stream of real per capita income in the region. This is summarized by the objective functional

$$\text{Max}_{u_t,\, t\in[1,T]} \quad J = \sum_{t=1}^{T-1} \frac{1}{(1+d)^t}\left(\frac{Y_{dt} D_t}{N_{st} + N_{ut}}\right) + W\left(\frac{Y_{dT} D_T}{N_{sT} + N_{uT}}\right), \tag{4.4}$$

where d is a known discount rate, N_{st} the supply of skilled workers, and N_{ut} the supply of unskilled workers. For simplicity, the labor force participation rate is assumed equal to 1. W is a composite discount factor

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[1] For another application of utility-preserving cost of living indices, see Taylor [1986], p. 17.

applied to all post-horizon earnings, and is derived by projecting terminal-period income into the indefinite future.

Let $u_t = \{TR_t, i_t\}$, where $0 < TR_t < 1$ and $0 < i_t < 1$, be the control vector, comprised of the income tax rate and the fraction of all public revenue to be devoted to current investment in physical infrastructure. By implication, $(1-i_t)$ is the share of public revenue devoted to current human capital investment. Assuming that all intergovernmental transfers must be earmarked for the provision of basic social services, the local government's budget constraint may be written as

$$TR_t Y_t = P_{gt} I_{gt} + P_{HCt} I_{HCt}, \tag{4.5}$$

where P_{gt} is the (given) price of public physical capital, and P_{HCt} the (given) price of human capital. In order to avoid feedback effects of public spending on the local economy, it is assumed that the payments for both public goods occur outside the region R; thus, both public physical capital and human capital are "imported" at given prices.

As a first approximation, public investment in human capital is hypothesized to transfer people from the unskilled to the skilled category. Overall productivity effects, embodied or disembodied, are recognized but ignored so as to simplify the analysis (see Becker et al., pp. 18-19). The postulated influence is shown as

$$\frac{TN_{st}}{N_{ut}} = a \cdot \ln\left(1 + \frac{I_{HCt}}{N_{ut}}\right), \tag{4.6}$$

where the fraction on the left-hand side denotes the proportion of unskilled workers transformed, and that on the right-hand side, the volume of human capital investment per unskilled worker. The collection of tax revenue, public human capital investment, and the related effect on the number of skilled and unskilled workers, are all taken to occur in an instant at the end of a period.

The total supply of either worker type in a given period is affected by natural increase at a given rate, public human capital investment in the previous period, and net migration, which occurs in an instant at the beginning of the period. Both unskilled and skilled labor supply are, therefore, known during the period, and are given by the identities

$$N_{s,t} = (1-n_{sd})\,N_{s,t-1} + n_s N_{u,t-1} + TN_{s,t-1} + NM_{s,t}, \text{ and} \tag{4.7}$$

$$N_{u,t} = N_{u,t-1} + (n_u - n_s)\,N_{u,t-1} - TN_{s,t-1} + NM_{u,t}. \tag{4.8}$$

For skilled labor, the birth rate is supposed to reflect the autonomous transformation of a given percentage, n_s, of the unskilled labor force into skilled workers in every period. The essential role of public investment in human capital, then, is to supplement this exogenous transformation process and potential migration of unskilled and skilled workers, and so to ensure adequate supply of skilled workers in any period. It is worthwhile to note that the skill inculcation process in Becker et al. is entirely autonomous and, hence, costless (pp. 18-19). In this model, however, supplementary transformation of workers can only occur at a cost to the local government and therefore to local tax-payers.

The rate of net inmigration of skilled (unskilled) workers responds positively to the relative regional-national skilled (unskilled) after-tax real wage and negatively to the corresponding unemployment rate. Thus,

$$\frac{NM_{s,t}}{N_{s,t-1}} = M_{1,s}\ln\left(\frac{(1-TR_{t-1})\,W_{s,t-1}D_{t-1}}{RW^N_{s,t-1}}\right) + M_{2,s}\ln\left(\frac{U_{s,t-1}}{U^N_{s,t-1}}\right), \text{ and} \tag{4.9}$$

$$\frac{NM_{u,t}}{N_{u,t-1}} = M_{1,u}\ln\left(\frac{(1-TR_{t-1})\,W_{u,t-1}D_{t-1}}{RW^N_{u,t-1}}\right) + M_{2,u}\ln\left(\frac{U_{u,t-1}}{U^N_{u,t-1}}\right), \tag{4.10}$$

where $M_{1,s}$, $M_{2,s}$, $M_{1,u}$ and $M_{2,u}$ are given parameters, and variables superscripted 'N' refer to the nation; by assumption, $M_{1,s} > 0$; $M_{2,s} < 0$; $M_{1,u} > 0$; and $M_{2,u} < 0$.

Cobb-Douglas production functions with constant returns to scale are assumed at the *firm* level in both the local and export sectors. Human capital investment, as already noted, merely transfers workers from the unskilled to the skilled category; the two labor types are treated as distinct factors of production. In each sector, firms are supposed to experience parametric external economies, so as to allow for constant, increasing or decreasing industry returns to scale[2]. Thus, for a *firm* in the export sector, the production function may be written as

$$q_x = b_x k_x^{\alpha 1} n_{s,x}^{\beta 1} n_{u,x}^{(1-\alpha 1-\beta 1)},$$

where k_x, $n_{s,x}$, and $n_{u,x}$ are, respectively, the level of private capital, the number of skilled workers, and the number of unskilled workers employed by the firm. Assuming n identical firms,

$$nq_x = b_x (nk_x)^{\alpha 1} (n.n_{s,x})^{\beta 1} (n.n_{u,x})^{(1-\alpha 1-\beta 1)},$$

or, letting capital letters denote industry totals, the *subjective* industry production function is given by

$$Q_x = b_x K_x^{\alpha 1} N_{s,x}^{\beta 1} N_{u,x}^{(1-\alpha 1-\beta 1)}.$$

Parametric externalities occur by letting b_x, which is taken as a constant by the firm, in fact relate to aggregate industry production:

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[2] This formulation of scale economies is due to Chipman [1970]. For its application in a different context, see Taylor [1986], pp. 4-5.

$b_x = \mu_x Q_x^{\phi 1}$, $\mu_x > 0$, $-\infty < \phi 1 < 1$.

This yields the *objective* industry production function

$$Q_{xt} = \mu_x^{1/(1-\phi 1)} K_{xt}^{\alpha 1/(1-\phi 1)} N_{s,xt}^{\beta 1/(1-\phi 1)} N_{u,xt}^{(1-\alpha 1-\beta 1)/(1-\phi 1)}. \tag{4.11}$$

The industry exhibits external economies of scale if $0 < \phi 1 < 1$, constant returns to scale if $\phi 1 = 0$, and external diseconomies of scale if $-\infty < \phi 1 < 0$. Similarly, the *objective* industry production function for the local sector is given by

$$Q_{Lt} = \mu_L^{1/(1-\phi 2)} K_{Lt}^{\alpha 2/(1-\phi 2)} N_{s,Lt}^{\beta 2/(1-\phi 2)} N_{u,Lt}^{(1-\alpha 2-\beta 2)/(1-\phi 2)}. \tag{4.12}$$

Private investment is assumed to occur in an instant at the beginning of any period; therefore, production in both sectors during a period is determined endogenously with a given capital stock. Skilled and unskilled worker employment during a period in both sectors are cast as short-run profit-maximizing derived demands; the resultant expressions are

$$N_{s,xt} = Q_{xt}^{\frac{(1-\phi 1)}{(1-\alpha 1)}} \mu_x^{\frac{-1}{(1-\alpha 1)}} K_{xt}^{\frac{-\alpha 1}{(1-\alpha 1)}} \left[\frac{(1-\alpha 1-\beta 1)}{\beta 1} \frac{W_{st}}{W_{ut}} \right]^{\frac{(\alpha 1+\beta 1-1)}{(1-\alpha 1)}}; \tag{4.13}$$

$$N_{u,xt} = \frac{(1-\alpha 1-\beta 1)}{\beta 1} \frac{W_{st}}{W_{ut}} N_{s,xt}; \tag{4.14}$$

$$N_{s,Lt} = Q_{Lt}^{\frac{(1-\phi 2)}{(1-\alpha 2)}} \mu_L^{\frac{-1}{(1-\alpha 2)}} K_{Lt}^{\frac{-\alpha 2}{(1-\alpha 2)}} \left[\frac{(1-\alpha 2-\beta 2)}{\beta 2} \frac{W_{st}}{W_{ut}} \right]^{\frac{(\alpha 2+\beta 2-1)}{(1-\alpha 2)}}; \text{ and} \tag{4.15}$$

$$N_{u,Lt} = \frac{(1-\alpha 2-\beta 2)}{\beta 2}\frac{W_{st}}{W_{ut}}N_{s,Lt}. \qquad (4.16)$$

Equations (4.13) through (4.16) refer successively to skilled and unskilled worker employment in the export and local sectors. The variables W_{st} and W_{ut} are the aggregate regional wage rates for skilled and unskilled labor. Each sector is individually a price-taker in the two labor markets.

Total regional employment of skilled (unskilled) labor is defined as the sum of the corresponding employment levels in the two sectors. Hence the identities

$$N_{s,et} = N_{s,xt} + N_{s,Lt}, \text{ and} \qquad (4.17)$$

$$N_{u,et} = N_{u,xt} + N_{u,Lt}. \qquad (4.18)$$

Regional unemployment rates for skilled and unskilled labor, $U_{s,t}$ and $U_{u,t}$, respectively, then follow from the identities

$$U_{s,t} = 1 - (N_{s,et}/N_{s,t}), \text{ and} \qquad (4.19)$$

$$U_{u,t} = 1 - (N_{u,et}/N_{u,t}). \qquad (4.20)$$

The aggregate real wage rate for skilled (unskilled) labor is taken to depend positively on the national real wage and the relative regional-national employment rate for skilled (unskilled) labor. This is written as

$$W_{st}D_t = W_{0,s}(RW_{st}^N)^{W_{1,s}}\left[\left(\frac{N_{s,et}}{N_{st}}\right)/E_{st}^N\right]^{W_{2,s}}, \text{ and} \tag{4.21}$$

$$W_{ut}D_t = W_{0,u}(RW_{ut}^N)^{W_{1,u}}\left[\left(\frac{N_{u,et}}{N_{ut}}\right)/E_{ut}^N\right]^{W_{2,u}}, \tag{4.22}$$

where $W_{0,s}$, $W_{1,s}$, $W_{2,s}$, $W_{0,u}$, $W_{1,u}$, and $W_{2,u}$ are all known parameters; RW_{st}^N and RW_{ut}^N are the national real wage rates for skilled and unskilled labor (assumed given); and E_{st}^N and E_{ut}^N are the national employment rates for skilled and unskilled labor (assumed given). $N_{s,et}$ and $N_{u,et}$ refer to total regional employment of skilled and unskilled labor respectively, as defined by the identities (4.17) and (4.18). N_{st} and N_{ut} refer to the total regional supply of skilled and unskilled labor, as defined by the identities (4.7) and (4.8). D_t is the endogenous price deflator defined by equation (4.3).

The price level in the local sector is determined endogenously by equating demand and supply in the local market. The demand function is derived from households' utility maximization with respect to the local and the imported good:

$$\frac{P_{Lt}Q_{Lt}}{Y_{dt}} = (1 - \sigma). \tag{4.23}$$

The supply function in the local sector is derived by short-run profit maximization:

$$Q_{Lt} = \left(\mu_L K_{Lt}^{\alpha 2}\left(\frac{\beta 2}{W_{st}}\right)^{\beta 2}\left(\frac{1-\alpha 2-\beta 2}{W_{ut}}\right)^{(1-\alpha 2-\beta 2)} P_{Lt}^{(1-\alpha 2)}\right)^{1/(\alpha 2-\phi 2)}. \tag{4.24}$$

Current private investment in each sector is assumed to be driven by a partial adjustment mechanism; the desired capital stock is derived from long-run cost minimization in the local sector and from long-run profit

maximization in the export sector. Noting that private investment occurs in an instant at the beginning of a period, the relevant identities are

$$K_{L,t} = K_{L,t-1} + I_{L,t} = K_{L,t-1} + \theta_L\left(K^*_{L,t-1} - K_{L,t-1}\right), \quad 0 < \theta_L < 1, \text{ and}$$

$$K_{x,t} = K_{x,t-1} + I_{x,t} = K_{x,t-1} + \theta_x\left(K^*_{x,t-1} - K_{x,t-1}\right), \quad 0 < \theta_x < 1.$$

Substituting the algebraic derivations for the desired capital stock, the level of private capital stock in the local sector is given by

$$K_{L,t} = \theta_L\left(\frac{\alpha 2}{r_{t-1}}\right)(1-\sigma)\, Y_{d,t-1} + (1 - \theta_L)\, K_{L,t-1}, \tag{4.25}$$

where r is an exogenous rate of interest, and θ_L is the speed of adjustment in the local sector. Analogously, the level of private capital stock in the export sector is given by

$$K_{x,t} = \left[\theta_x Q_{x,t-1}^{\frac{(\alpha 1-\phi 1)}{\alpha 1}} \mu_x^{\frac{-1}{\alpha 1}} \left(\frac{\beta 1}{W_{s,t-1}}\right)^{\frac{-\beta 1}{\alpha 1}} \left(\frac{1-\alpha 1-\beta 1}{W_{u,t-1}}\right)^{\frac{\alpha 1+\beta 1-1}{\alpha 1}} P_{x,t-1}^{\frac{\alpha 1-1}{\alpha 1}}\right] + (1-\theta_x)\, K_{x,t-1}, \tag{4.26}$$

where θ_x is the speed of adjustment in the export sector.

In any period, public infrastructure is assumed to exert a limiting influence on total regional production. This may be shown as

$$Q_{xt} + Q_{Lt} \leq B.K_{gt}, \tag{4.27}$$

where 1/B reflects a fixed requirement of infrastructure per unit of regional output (Schroeter and Azzam, pp.994-5). The present form anticipates the more precise specification of one constraint for each sector.

The stock of public physical capital at the beginning of a time period is the sum of the stock at the beginning of the previous period and

current public investment at the end of the previous period; allowing for potential depreciation, this is given by the identity

$$K_{g,t} = (1-DEP_g)\, K_{g,t-1} + I_{g,t-1}. \tag{4.28}$$

Rewriting the government's budget constraint (equation (4.5)),

$$P_{gt} I_{gt} = i_t[TR_t Y_t], \text{ and} \tag{4.29}$$

$$P_{HCt} I_{HCt} = (1-i_t)[TR_t Y_t] \tag{4.30}$$

where i_t is the allocation of total public expenditure towards physical infrastructure investment in period t. The local government's problem, then, is to find time paths for the income tax rate TR_t and the allocation ratio i_t so as to maximize the objective functional defined by the identity (4.4).

The model has 16 endogenous variables: the two wage rates for skilled and unskilled labor, W_s and W_u; skilled and unskilled employment levels in the two sectors, $N_{s,X}$, $N_{u,X}$, $N_{s,L}$, and $N_{u,L}$; total skilled and unskilled employment levels, $N_{s,c}$ and $N_{u,c}$; regional unemployment rates for skilled and unskilled labor, U_s and U_u; production levels in the two sectors, Q_X and Q_L; the price level in the local sector, P_L; the price deflator, D; gross regional income, Y; and disposable regional income, Y_d. By construction, both kinds of labor supply, private capital stocks in both sectors, and the stock of public infrastructure change from one period to the next, but remain fixed within any period.

4.3 Model Calibration and Solution Strategies

Technically speaking, the model may be classified as a closed-loop, discrete-time optimal control problem with a free end point and a fixed

time horizon. Solving it as such, however, presents some practical problems. Grinold [1980] suggests that "the artificial selection of a final period can lead to distortions in the solution of the model", and uses the term "end effects" for such distortions (p. 218). In general, end effects are greater, the closer one gets to the terminal planning period. In the context of linear programming models, Grinold presents five different techniques to minimize end effects and to make a smooth transition between the planning period and the period after the planning horizon. Three of these techniques are readily transferable to the nonlinear case: (i) the *truncation method* simply ignores the future and sets all variables equal to zero beyond the terminal period (p. 220); (ii) the *prescient approach* specifies some notional values for all variables beyond the planning horizon, thus assuming some knowledge of future states (p. 220); and (iii) the *salvage value technique* specifies the net present value embodied in any given variable (p. 222).

Given the number of state variables in the model, and an equal number of costate variables, the transversality conditions corresponding to the terminal period were found extremely difficult to articulate. So also, in a dynamic programming context, there was no handy way of choosing one of a large number of possible final states. Procedural limitations, then, made it expedient to solve the model simply as a nonlinear programming problem. In terms of specifying end-point conditions, terminal-period real per capita income was projected into the indefinite future, and the discounted value of this constant stream was used as the salvage value. This method implicitly replicates the terminal-period scenario into the future. It is worth mentioning that although the treatment of labor supply, private capital, and public physical capital imposes a recursive structure on the model, the model cannot be solved recursively; this is so because the planner needs to be able to see the future benefits accruing from present public expenditures.

Owing to the high degree of simultaneity and endogeneity in the model, preliminary attempts to derive an analytical solution via the Hamiltonian and the maximum principle proved futile. Parameter estimates then became necessary to obtain a numerical solution. Since the stated objective was to demonstrate the mathematical validity of the model *prior to* its empirical application, an *ad hoc* procedure was used for calibration. Except where otherwise stated, all parameter values were reasonable guesses made in the overall interest of the internal consistency of the model. So also, as a first step, the initial values for all the endogenous variables were so chosen as to make the model mathematically tractable.

In the utility function, the utility elasticity of the import good, σ, is set equal to 0.7. This implies a utility elasticity of 0.3 for the local good. These values help to control the deflator (equation (4.3)) and the local sector price (equation (4.23)).

The import good is assumed to be the numeraire, so that $P_m = 1$. Since both the public goods--physical capital and human capital--are assumed to be imported, it follows that $P_g = P_{HC} = 1$ (equations (4.5), (4.29) and (4.30)). The discount rate, d, is set at 3% (equation (4.4)), and the rate of interest, r, at 10% (equation (4.25)). In order to ensure appropriate scaling in terms of relative prices, the rate of interest, r, is entered as 0.01 instead of as 0.1. The rate of depreciation of public infrastructure, DEP_g, is assumed to be 3% (equation (4.28)). The speeds of adjustment of private capital stock in the local and export sectors, θ_L and θ_X, are both set at 3.25% (equations (4.25) and (4.26)); these values are critical to the solution process, since they absolutely control the intertemporal dynamics in the model; the chosen values prevent excessive increases or decreases in private capital stocks from period to period. So also, the migration equation coefficients are chosen so as to prevent wide intertemporal fluctuations in labor supply; in the skilled migration equation (4.9), the responsiveness to the relative regional-national

skilled wage, $M_{1,s}$, is set at 0.05, and the responsiveness to the relative regional-national skilled unemployment rate, $M_{2,s}$, at -0.03. Their counterparts in the unskilled migration equation (4.10), $M_{1,u}$ and $M_{2,u}$, are set at 0.038 and -0.042. The greater absolute value of $M_{1,s}$ relative to $M_{2,s}$ implies that skilled labor is more responsive to wage differentials than to relative unemployment rates; the opposite is true of unskilled labor.

The rate of natural increase for unskilled labor, n_u, is set at 0.005, implying that unskilled labor multiplies at a rate of 0.5% every period; the "birth rate" for skilled labor, n_s, is assumed equal to 0.002, meaning that 0.2% of the unskilled labor force transforms itself into skilled labor every period. It follows that the effective rate of natural increase of unskilled labor is equal to 0.003 (equations (4.7) and (4.8)). The death rate for skilled labor, n_{sd}, is assumed to be 0.001, or 0.1%. In equation (4.6), which reflects the cost of transforming unskilled into skilled workers through public human capital investment, the coefficient *a* is set at an experimental value of 0.032, which is low enough to control the number of people transformed in any period, and high enough actually to effect transformation as required, within the local government's limited means.

In equation (4.27), which specifies the role of physical infrastructure as a constraint on regional production, the coefficient *B* is assumed equal to 0.67, reflecting a fixed requirement of 1.5 units of infrastructure per unit of regional output. This requirement is low enough to permit increasing production within the government's budget constraint, and high enough actually to call for current investments in infrastructure through local taxation.

The national real wage for skilled labor, RW_{st}^N, is taken as $24960 per year, assuming an hourly wage of $12 and a 40-hour week. For analytical purposes, it is set equal to 1. The national real wage for unskilled labor, RW_{ut}^N, is assumed to be $16960 per year, reflecting an hourly rate of $8.15. Relative to RW_{st}^N, it is set at 0.68. The skilled and unskilled

employment rates at the national level, E_{st}^N and E_{ut}^N, are set at 92% and 90% respectively. In order to keep the regional skilled and unskilled real wage rates roughly true to their national counterparts, the parameters in the two wage equations ((4.21) and (4.22)) are assumed as $W_{0,s}$ = 1.003, $W_{1,s}$ = 0.95, $W_{2,s}$ = 1.2, $W_{0,u}$ = 1.002, $W_{1,u}$ = 0.92, and $W_{2,u}$ = 1.15.

With respect to the production functions (equations (4.11) and (4.12)), moderately increasing returns to scale are assumed in the export sector, in contrast with constant returns to scale in the local sector; thus, $\phi 1$ = 0.1 and $\phi 2$ = 0. Factor shares from U.S. manufacturing data for 1987 are used as proxies for the exponents on skilled and unskilled labor and private capital in the export sector. The total value of shipments net of the cost of materials (U.S. Statistical Abstract, 1990, p. 741) is used for apportionment among the three factors. Skilled labor is assumed to include executive and managerial employees, professional employees, technicians and precision production workers. Unskilled labor is taken to include sales support personnel, administrative (including clerical) personnel, other service workers, machine operators, transportation and material moving workers, and handlers, equipment cleaners, helpers, and laborers. Becker et al. use a similar occupational definition of labor skills to correspond to their segmented labor markets (pp. 275-276). Employment data for these categories are combined with corresponding median weekly earnings data (Handbook of Labor Statistics, August 1989, pp. 110, 167) to derive total annual earnings and therefore the factor shares of skilled and unskilled labor. The share of private capital is derived as a residual. These calculations yield the values $\alpha 1$ = 0.6 (for private capital), $\beta 1$ = 0.21 (for skilled labor) and $(1-\alpha 1-\beta 1)$ = 0.19 (for unskilled labor) for the export sector. The sole remaining parameter is arbitrarily set at μ_x = 1.285.

A similar procedure is used with regard to the local sector, which is treated as a collection of two-digit SIC service industries (hotels, motels, etc.; personal services; business services; automotive repair,

etc.; motion pictures; amusement and recreation services; health services; legal services; job training, etc.; engineering, architectural and surveying services; accounting, auditing and bookkeeping services; . . .). Final factor shares are derived as averages over these industries (Handbook of Labor Statistics, August 1989, p. 110; Census of Service Industries, 1987, pp. 2-11, 2-12). The parameter values so derived are $\alpha 2$ = 0.33 (for private capital), $\beta 2$ = 0.44 (for skilled labor), and $(1-\alpha 2-\beta 2)$ = 0.23 (for unskilled labor). The intercept parameter is again arbitrarily set at μ_L = 1.25.

The fully calibrated model is furnished below for ready reference.

Objective functional:

$$Max \quad J = \sum_{t=1}^{T-1} \frac{1}{(1.03)^t}\left(\frac{Y_{dt}D_t}{N_{st}+N_{ut}}\right) + W\left(\frac{Y_{dT}D_T}{N_{sT}+N_{uT}}\right); \tag{4.31}$$

Gross regional income:

$$Y_t = P_{Lt}Q_{Lt} + 1.2Q_{Xt}; \tag{4.32}$$

Disposable regional income:

$$Y_{dt} = (1-TR_t)\, Y_t; \tag{4.33}$$

Price deflator:

$$D_t = \left(\frac{0.7}{1}\right)^{0.7}\left(\frac{0.3}{P_{Lt}}\right)^{0.3}; \tag{4.34}$$

Unskilled to skilled worker transformation from public human capital investment:

$$\frac{TN_{st}}{N_{ut}} = 0.032 \ln\left(1+\frac{I_{HCt}}{N_{ut}}\right); \tag{4.35}$$

Skilled labor supply identity:

$$N_{s,t} = 0.999N_{s,t-1} + 0.002N_{u,t-1} + TN_{s,t-1} + NM_{s,t}; \tag{4.36}$$

Unskilled labor supply identity:

$$N_{u,t} = 1.003N_{u,t-1} - TN_{s,t-1} + NM_{u,t}; \tag{4.37}$$

Rate of skilled net migration:

$$\frac{NM_{s,t}}{N_{s,t-1}} = 0.05 \ln\left(\frac{(1-TR_{t-1})W_{s,t-1}D_{t-1}}{1}\right) - 0.03 \ln\left(\frac{U_{s,t-1}}{0.08}\right); \tag{4.38}$$

Rate of unskilled net migration:

$$\frac{NM_{u,t}}{N_{u,t-1}} = 0.038 \ln\left(\frac{(1-TR_{t-1})W_{u,t-1}D_{t-1}}{0.68}\right) - 0.042 \ln\left(\frac{U_{u,t-1}}{0.10}\right); \tag{4.39}$$

Export sector production function:

$$Q_{Xt} = 1.285^{1.1111} K_{Xt}^{0.6667} N_{s,Xt}^{0.2333} N_{u,Xt}^{0.2111}; \tag{4.40}$$

Local sector demand function:

$$\frac{P_{Lt}Q_{Lt}}{Y_{dt}} = 0.3; \tag{4.41}$$

Local sector supply function:

$$Q_{Lt} = 1.25^{3.0303} K_{Lt} \left(\frac{0.44}{W_{st}} \right)^{1.3333} \left(\frac{0.23}{W_{ut}} \right)^{0.697} P_{Lt}^{2.0303}; \quad (4.42)$$

Skilled employment, export sector:

$$N_{s,Xt} = 1.285^{-2.5} Q_{Xt}^{2.25} K_{Xt}^{-1.5} \left[\frac{0.19 W_{st}}{0.21 W_{ut}} \right]^{-0.475}; \quad (4.43)$$

Unskilled employment, export sector:

$$N_{u,Xt} = \left[\frac{0.19 W_{st}}{0.21 W_{ut}} \right] N_{s,Xt}; \quad (4.44)$$

Skilled employment, local sector:

$$N_{s,Lt} = 1.25^{-1.4925} Q_{Lt}^{1.4925} K_{Lt}^{-0.4925} \left[\frac{0.23 W_{st}}{0.44 W_{ut}} \right]^{-0.3433}; \quad (4.45)$$

Unskilled employment, local sector:

$$N_{u,Lt} = \left[\frac{0.23 W_{st}}{0.44 W_{ut}} \right] N_{s,Lt}; \quad (4.46)$$

Total regional skilled employment:

$$N_{s,et} = N_{s,Xt} + N_{s,Lt}; \quad (4.47)$$

Total regional unskilled employment:

$$N_{u,et} = N_{u,Xt} + N_{u,Lt}; \quad (4.48)$$

Regional skilled unemployment rate:

$$U_{s,t} = 1 - (N_{s,et}/N_{s,t}); \tag{4.49}$$

Regional unskilled unemployment rate:

$$U_{u,t} = 1 - (N_{u,et}/N_{u,t}); \tag{4.50}$$

Real skilled wage rate:

$$W_{st}D_t = (1.003)\,(1)^{0.95}\left[\frac{N_{s,et}/N_{s,t}}{0.92}\right]^{1.2}; \tag{4.51}$$

Real unskilled wage rate:

$$W_{ut}D_t = (1.002)\,(0.68)^{0.92}\left[\frac{N_{u,et}/N_{u,t}}{0.90}\right]^{1.15}; \tag{4.52}$$

Private capital stock, export sector:

$$K_{X,t} = 0.0325\left[(1.285)^{-1.67}(Q_{X,t-1})^{0.83}\left(\frac{0.21}{W_{s,t-1}}\right)^{-0.35}\left(\frac{0.19}{W_{u,t-1}}\right)^{-0.32}(1.2)^{-0.67}\right] + 0.9675K_{X,t-1}; \tag{4.53}$$

Private capital stock, local sector:

$$K_{L,t} = 0.0325\left(\frac{0.33}{0.01}\right)(0.3)\,Y_{d,t-1} + 0.9675K_{L,t-1}; \tag{4.54}$$

Public infrastructural constraint on regional production:

$$Q_{Xt} + Q_{Lt} \leq 0.67K_{g,t}; \tag{4.55}$$

Public infrastructural stock identity:

$$K_{g,t} = 0.97K_{g,t-1} + I_{g,t-1}; \tag{4.56}$$

Public infrastructural investment:

$$I_{g,t} = i_t[TR_tY_t]; \text{ and} \tag{4.57}$$

Public human capital investment:

$$I_{HCt} = (1-i_t)[TR_tY_t]. \tag{4.58}$$

4.4 Initial Values

As noted earlier, initial values for all endogenous variables are so chosen as to ensure the mathematical tractability of the model. The real skilled wage is set at 1.0161 relative to the national real skilled wage of 1, to correspond to a regional skilled employment rate of 93% (relative to the national skilled employment rate of 92%). Similarly, the real unskilled wage is set at 0.7117 relative to the national real unskilled wage of 0.68, to correspond to a regional unskilled employment rate of 91% (relative to the national unskilled employment rate of 90%).

The price deflator is arbitrarily pegged at 0.6. The definition of the price deflator then implies a corresponding value of 0.7163 for the local sector price. In order to ensure a production level in the range of 10^6 in the local sector, the level of private capital stock in the local sector is arbitrarily fixed at 6 10^7. Values for the real skilled and unskilled wages, the local sector price, the price deflator, and the private capital stock are used in the supply function of the local sector to obtain a sectoral production level of 3.1664 10^6.

The two real wage rates, the private capital stock, and the production level are substituted into the derived demand equations in the local sector to obtain sectoral employment levels for skilled and unskilled labor, at 0.5893 10^6 and 0.4398 10^6, respectively. The demand equation of the local sector is used to calculate regional disposable income at 7.5603 10^6, given the local sector price and output level. An arbitrary tax rate of 5% is assumed to derive gross regional income at 7.959 10^6. The gross income identity then yields the output level in the export sector, at 4.7423 10^6, corresponding to the above values of the local sector price and output, and an exogenous export good price of 1.2.

In order to ensure roughly comparable employment levels in the export and local sectors, the level of private capital stock in the export sector is fixed at an experimental value of 8 10^5. Substituting the values for the real skilled and unskilled wage rates, export sector output, and export sector private capital stock in the derived demand equations, sectoral employment levels for skilled and unskilled labor are found to be 0.6936 10^6 and 0.8959 10^6, respectively.

It is worth noting that the existence of increasing returns to scale in the export sector, as opposed to constant returns to scale in the local sector, permits a comparable level of output with a smaller stock of private capital.

The initial stock of public infrastructure is set at 1.2 10^7, a level just sufficient to allow the above output levels in the two sectors. The remaining policy variable, the allocation ratio between physical infrastructure and human capital investment, is arbitrarily assumed to be equal to 1, i. e., the two expenditure types receive a 50% share each.

Total skilled and unskilled employment levels are obtained as the corresponding sums of sectoral employment levels. Skilled and unskilled labor supply are initialized at 1.4 10^6 and 1.5 10^6, to ensure employment rates of 93% and 91%, respectively.

As a consistency check, the above initial values are used in the Newton-Raphson procedure[3] in *Mathematica*[4] to solve the following simultaneous system of 12 equations: the two wage equations, the four derived demand equations, the export sector production function, the demand and supply functions in the local sector, the deflator equation, and the gross and disposable income identities. The solution values from *Mathematica* are used as initial values in the nonlinear optimization program in GAMS 2.25: real skilled wage 1.0092; real unskilled wage 0.7041; export-sector output 4.7591 10^6; local-sector output 3.1954 10^6; export-sector skilled employment 0.6981 10^6; export-sector unskilled employment 0.9053 10^6; local-sector skilled employment 0.5965 10^6; local-sector unskilled employment 0.4469 10^6; local-sector price 0.7124; price deflator 0.6010; gross regional income 7.9873 10^6; and, disposable regional income 7.5879 10^6.

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[3] For an effective description of the procedure, see Maron [1982].

[4] See Wolfram [1991].

CHAPTER 5
MODEL SOLUTION

5.1 Introduction

The fully calibrated model is executed as a nonlinear programming problem in GAMS 2.25 (see Brooke et al. [1988]). For an arbitrary planning horizon of 10 periods, the model is solved for three different versions of the public sector. In scenario 1, the government can collect income tax revenues just sufficient to maintain a fixed level of physical infrastructure, i.e., to offset depreciation in public capital stock at 3% every period; thus, the income tax rate is the only control variable. In scenario 2, the government can use the local income tax to augment the region's stock of physical infrastructure, as and when required; thus, both the income tax rate and physical capital investment serve as control variables. In scenario 3, the government can choose to invest in physical infrastructure and/or human capital; this version has three control variables, the income tax rate and the two expenditure types. In view of the complementary relationship between infrastructure and regional output, the region may be expected to perform better in scenario 2 than in scenario 1, since it has the ability to ease infrastructural constraints. By the same token, scenario 3 can be expected to outdo scenario 2, because of its ability to ease manpower constraints. The results are presented by scenario in the three tables in Appendix A. The behavior of every key variable across scenarios is presented in graphical form in Appendix B, for comparative purposes.

5.2 Scenario 1

With given supplies of unskilled and skilled labor, and given endowments of public infrastructure and private capital in the two

sectors, the economy registers a level of activity roughly around the national norm, in period 1--as reflected in the two wage rates and unemployment rates. Overall, the two wage rates, the two unemployment rates, and regional disposable income (both total and per capita) follow the export sector, as periods 7 through 10 make abundantly clear. The domination of the wage and employment rates by the export sector may be explained in terms of the two sectoral production functions: with increasing returns to scale, the output elasticities of skilled and unskilled labor in the export sector are 0.23 and 0.21 respectively. The corresponding output elasticities in the local sector are 0.44 and 0.23, with constant returns to scale. The reciprocals of these output elasticities (4.35 and 4.76 in the export sector and 2.27 and 4.35 in the local sector) define the percentage change in skilled and unskilled labor inputs following a percentage change in sectoral output. Clearly, when the two sectors move in opposite directions over time, the export sector has a larger relative influence on employment levels and, therefore, on wage rates. The tendency of the export sector to dominate gross income movements stems from its larger income multiplier, viz., the sector price, relative to the local sector. Disposable income movements are gross income movements adjusted for tax rate changes.

In general, the local sector expands output and employment in periods when the economy is otherwise shrinking (i.e., when export sector output and employment and regional disposable income go down and regional unemployment rates go up); the only exceptions are periods 2 and 6, when both sectors show very modest increases. This behavior may be explained on the following lines: a steadily growing stock of private capital in the local sector contrives to move the supply curve outwards in every period, while upward or downward movements in regional income serve to move the sectoral demand curve outwards or backwards contemporaneously. Together, these demand and supply shifts can readily explain the joint behavior of local sector output and price in 6 of the 9 periods after the first, viz.,

in periods 2, 3, 5, 6, 7 and 10. In all these periods, output invariably increases, while price either increases or decreases, depending on the direction and magnitude of the shift in the demand curve relative to an outward shift in the supply curve. Thus, decreases in regional disposable income imply relatively smaller backward shifts in the demand curve in periods 3, 5, 7 and 10, so that output increases while price falls. In periods 2 and 6, small increases in disposable income move the demand curve outward relatively more, thereby increasing both output and price modestly. In periods 4, 8 and 9, however, output decreases and price increases, as rising real wage rates bring about temporary backward shifts in the supply curve.

Following a sharp slump in period 7 and a sharp expansion in period 9, the economy seems inclined to return to its more-or-less steady trend of the first 6 periods. It is tempting to ask whether the slump of period 7 results from a marginal increase in the tax rate from 4.5% to 4.7%, and whether the increased growth in period 9 comes from a marginal decrease in the tax rate from 4.5% to 4.4%. The same sharp responses are not true, however, of periods 3 and 4, when the tax rate first goes up from 4.5% to 4.6% and then goes back down to 4.5%. As such, it is difficult to explain the instability in the economy from period 7 onwards.

Endogenous migration responses help to offset sharp ups and downs in the economy, but with a lag; in period 8, a continued slump is prevented by substantial outmigration of unskilled and skilled labor, at 1.4% and 1.7%, respectively. The significant cutback in labor supply results in higher wage rates, higher employment levels, and lower unemployment rates. By contrast, in period 10, a continued upward trend is arrested by sharply increased inmigration rates, at 1.2% each for unskilled and skilled labor. As a result of increased labor supply, wage rates and employment levels are held down, and unemployment rates are increased. If migration propensities were in fact constrained, it is likely that the economy would follow significantly lower or higher paths for longer stretches of time.

As might be expected, the complementary nature of public infrastructure in the production process renders sectoral private capital stocks less important. Thus, the local sector both increases and decreases even as its capital stock increases all along. In the export sector, capital stock decreases sharply in period 8 while output increases as sharply; in period 9, capital stock decreases while output increases; and, in period 10, capital stock increases but output decreases. If the economy must abide by the infrastructural constraint, it is hard to say, *a priori*, which of the two sectors will or must adjust. The inability of private capital stocks to adjust in the short term brings about consistent movements of sectoral output and employment as a result of factor substitution: in periods when output increases while capital stock decreases, there is a more than proportionate increase in employment levels in the sector, and vice versa when output decreases while capital stock increases. With respect to the infrastructural constraint, the economy shows a slack through the first 8 periods, ranging between 0.47% (in period 6) and 1.48% (in period 7).

Overall, the economy's skilled real wage is lower than the national--and its skilled unemployment rate higher than the national--only in periods 3 and 7. Contrary to expectations, however, the unskilled real wage is lower than the national in period 7 only, although the unskilled unemployment rate is above the national in 6 periods (1-3, 5-7). This suggests a downward bias in the elasticity of the unskilled real wage with respect to the relative regional-national unskilled employment rate (equation (4.52)).

5.3 Scenario 2

In period 1, the economy shows a skilled wage lower than the national, consistent with a skilled unemployment rate higher than the national. In the unskilled labor market, however, both the unemployment rate and the wage rate are higher than the corresponding national rates,

and point once again to a miscalibrated unskilled wage equation. As in scenario 1, wage and unemployment rates follow the export sector; unlike in scenario 1, however, regional disposable income is amazingly steady, ostensibly as a result of well-matched adjustments in the two sectors. This is particularly interesting in view of the fact that the local income tax rate varies much more in scenario 2 relative to scenario 1, where the variations in the tax rate are negligible although those in disposable income are not. Thus, in scenario 2, regional gross income adjustments offset changes in the tax rate. Why this is true of scenario 2 alone is not obvious.

Such behavior is strikingly evident in periods 8, 9 and 10: in period 8, the tax rate is highest, at 7.4%, but the export sector peaks in the period, as do the two wage rates, and unemployment rates are at their lowest. In period 9, by contrast, the tax rate is lowest, at 0.2%, but export sector output and the two wage rates are at their lowest, and regional unemployment rates are at their highest. All these extreme tendencies have virtually no effect on disposable income! So also, in period 10, the tax rate goes up from 0.2% to 4.2%; yet, export sector output and the two wage rates go up sharply, and unemployment rates go down significantly.

Self-correcting adjustments in migration flows are clearly seen in periods 9 and 10. The sharp increase in wage rates in period 8 is followed by substantial inmigration of unskilled (1.2%) and skilled workers (1%). The resultant boost to both kinds of labor supply pulls wage and employment rates back down in period 9. A continued slump into period 10 is prevented by substantial outmigration (1.6% for skilled workers and 2.3% for unskilled workers) in period 10, forcing a sizeable cutback in labor supply and corresponding increases in wage and employment rates.

As in scenario 1, shifts in the supply and demand curves in the local sector can be used to explain the combined behavior of output and price. In periods 2, 4, 5 and 9, output goes up and price decreases, as

a result of a larger outward shift in the supply curve relative to an outward or backward shift in the demand curve--decreases in disposable income in periods 2 and 4 imply backward shifts in demand in those periods, and increases in disposable income imply outward demand shifts in periods 5 and 9. In period 6, output decreases substantially and price goes down negligibly, pointing to a larger backward shift in the demand curve relative to an outward shift in the supply curve. However, in periods 3, 7, 8 and 10, output decreases and price increases, as rising real wage rates move the supply curve backwards, more than offsetting the effect of a growing capital stock in the sector.

That the public infrastructural constraint is more important than the level of sectoral private capital stock is manifested once again, in scenario 2: in the local sector, output goes up and down despite a continuously growing private capital stock, implying corresponding labor input adjustments. In the export sector, higher levels of output are achieved with lower levels of capital stock in periods 3, 4, 6, 7, and 10. Smaller output levels with bigger capital stocks are seen in periods 5 and 9. In period 8, the increase in output is much greater than that in the capital stock. Such reciprocal trends have direct implications in the labor market as a result of factor substitution, as noted under scenario 1.

Overall, the economy's skilled and unskilled real wage rates are lower than the national in 3 and 1 of the 10 periods, respectively. The skilled and unskilled unemployment rates are higher than the national rates of 8% and 10% in 4 and 6 of the 10 periods, respectively. As in scenario 1, the economy is relatively stable in the first 6 periods, and a very unstable phase over periods 7 through 9 is followed by a return to the stable range in period 10.

In terms of public infrastructure, the economy has an initial slack of 1.02% in period 1, and 0.74% in period 2; a higher tax rate of 5.2% in period 4 is followed by a slack of 0.41% in period 5. The government chooses to increase its infrastructural stock beyond the fixed level of

scenario 1 only in 2 periods (8 and 9). The increase in period 8 follows a relatively higher tax rate of 5.6% in period 7, and the higher level of infrastructure, 1.2046E+7, is fully utilized. The increase in period 9 is a result of a sharply raised tax rate from 5.6% to 7.4% in period 8. A slack of 2.65% in period 9 implies that this is a case of overtaxation; the level of infrastructure actually put to use in period 9 would be 97.35% of the level in place, i.e., 1.1958E+7, which is almost equal to the fixed level of 1.2E+7 in scenario 1. Whether this ability of the region to create infrastructure is responsible for the marginally higher value of the objective function in scenario 2 relative to scenario 1 is not clear.

5.4 Scenario 3

The economy begins in period 1 at a slightly lower level than the national, as reflected in the lower-than-national skilled wage rate and the higher-than-national unskilled and skilled unemployment rates.

Scenario 3 is different from scenarios 1 and 2 in that the two wage rates do not follow the export sector as closely. The correspondence is evident only in periods 2, 3, 6, and 10. In period 4, both sectors are growing, so that the rise in the two wage rates is greater than that in export sector output and employment. In period 5, the export sector expands somewhat and the local sector shrinks somewhat. The two wage rates follow the local sector but in fact fall more than local sector output and employment. In period 7, both sectors shrink, the local sector moreso than the export sector; as a result, the wage rates fall relatively more than export sector output and employment. In period 8, a sharp increase in the local sector overshadows a very modest increase in the export sector, effecting a sharp increase in the two wage rates. In period 9, a negligible increase in the export sector is countered by a substantial fall in the local sector, which pulls the wage rates down sharply.

The general pattern is easily explained as before, in terms of the unskilled and skilled labor elasticities of export and local sector output. When there are sharp offsetting movements in the two sectors, wage rates follow the export sector; in periods when the change in the local sector is much greater than an opposite change in the export sector, the wage rates follow the local sector; when the two sectors move in the same direction, they take the wage rates along, but the overall change in the wage rates is greater than that in either sector.

The economy is generally more unstable than in scenarios 1 and 2: this is clearly seen in the behavior of the wage rates and regional disposable income. Disposable income is much steadier than the wage rates, except in periods 7 and 8. As before, a relatively stable trend in the first 6 periods is followed by a very unstable phase in periods 7 through 9. While the wage rates continue to be unstable into period 10, disposable income returns to its initial stable state in period 10. This is possible only because of the low tax rate in period 10, which offsets a sharp drop in gross regional income as a result of the slump in the export sector.

The very sharp fall in disposable income in period 7 is a result of a sharp increase in the tax rate from 4.4% in period 6 to 9.3% in period 7. Interestingly, the brunt of this fall is borne by the local sector. In period 8, the tax rate is lowered from 9.3% to 0.8%, and disposable income shoots up from its lowest level to its highest level, and this increase is again mostly in the local sector. This is the opposite of scenario 1, where sharp upward or downward movements in disposable income are absorbed in the export sector.

In the local sector, demand and supply curve shifts can explain the joint behavior of sector output and price in all the 9 periods after the first. In periods 4 and 8, the demand curve moves out more than the supply curve, causing an increase in both output and price (the greater outward shift in the demand curve is consistent with the substantial

increases in disposable income in those periods); in periods 5, 7 and 9, the demand curve moves back more than the supply curve moves out, so that both price and output decrease (the greater backward shift in the demand curve is consistent with the substantial decreases in disposable income in those periods); in periods 6 and 10, the demand curve moves out less than the supply curve moves out, and output increases while price decreases (the moderate increase in disposable income in those periods explains the smaller outward shift in the demand curve). Periods 2 (output decreases and price increases) and 3 (output falls negligibly at a constant price) are explained by temporary backward shifts in the supply curve resulting from rising real wage rates.

Unlike in scenario 2, where tax rate changes are offset by gross income changes to keep disposable income stable, scenario 3 shows tax rate changes having direct effects on disposable income. Thus, in period 4, a significant drop in the income tax rate from 5.4% to 4.6% results in a straightforward increase in disposable income; the opposite occurs in period 5. A very sharp tax rate increase in period 7, from 4.4% to 9.3%, results in a severe decrease in disposable income; once again, the reverse occurs in period 8. In period 9, an increase in the tax rate from 0.8% to 5.2% is mirrored in a sharp drop in disposable income. The opposite is true of period 10. Despite the low tax rate and the increase in disposable income in period 10, the unemployment rates are seen to increase sharply; this is because there is a sharp drop in gross income, as export sector output and local sector price fall substantially.

The option to make human capital investments is exercised in 5 of the 10 periods, in varying degrees. While physical infrastructure receives a 100% allocation of public funds in 5 periods, human capital gets a 100% allocation in only 1 period. In other periods, the allocation to physical infrastructure varies between 44% (in period 10) and 65% (in period 5). The economy shows excess infrastructure in only 3 periods: 1.24% in period 1, 0.78% in period 7, and 1.63% in period 8. Although tax

revenues are fully devoted to infrastructural investments in 5 periods, the total stock of infrastructure goes beyond the initial stock only in 1 period. In the other periods, current investments are not sufficient to offset the depreciation of stock. The almost negligible slack in period 7 is not a result of overtaxing in period 6; rather, it follows from a marked reduction in economic activity in period 7, thanks to a high tax rate of 9.3% in that period. The much larger pool of public revenue in period 7 is invested fully in infrastructure, explaining the modest slack of 1.63% in period 8.

The government's ability to make human capital investments enables the tax rate to regulate labor supply in two ways: since migration is a function of relative after-tax wage rates, a high tax rate either slows down inmigration or hastens outmigration of both labor types, thereby reducing both unskilled and skilled supply; however, human capital investment following a high tax rate increases skilled supply but decreases unskilled supply. This is the essential difference between the two. In period 2, there is sizeable outmigration of both unskilled and skilled labor, at 0.9% and 0.7% respectively. Unskilled labor supply is further reduced by public transformation of unskilled workers into skilled workers. This serves to offset the decrease in skilled labor supply somewhat. In period 6, there is very modest inmigration of both unskilled and skilled workers. Public investment in period 5 adds to the skilled labor supply further; by removing more unskilled workers than inmigration adds, it more than offsets this addition to the unskilled labor force. In period 9, there is fair-sized inmigration of both labor types, and public investment in period 8 partially offsets the increase in unskilled supply. In period 10, as in period 2, public investment in period 9 further reduces the unskilled labor supply beyond the modest loss from outmigration (0.4%). But unlike in period 2, the number of skilled workers created is greater than the number lost to migration, so that there is a net

(endogenous) addition to the skilled workforce; thus, human capital investment actually overwhelms the migration effect in this case.

Scenario 3 provides further evidence on the greater effective importance of public infrastructure relative to private capital stocks: in the local sector, as before, output goes up and down despite a growing trend in sectoral capital stock. In the export sector, higher levels of output are registered with smaller capital stocks, in periods 2-4, 8 and 9. In period 5, capital stock increases marginally, but the output level goes up relatively more. In period 6, capital stock increases marginally whereas output falls appreciably. In period 7, capital stock decreases relatively more than output. In period 10, output falls relatively much more than capital stock. In all cases, short-term labor market adjustments take place as a result of factor substitution.

Overall, the region's skilled real wage is lower than the national--and both unemployment rates are higher than the national--in 5 periods; owing to miscalibration, however, the unskilled real wage is lower than the national only in 2 periods.

5.5 Concluding Remarks

The three scenarios return the following values for the objective functional (discounted stream of real per capita disposable income): 54.259 (scenario 1); 54.308 (scenario 2); and 54.632 (scenario 3). In order to test whether the instability in the economy from period 7 onwards results from a foreshortened planning horizon, all three scenarios were rerun for an extended horizon of 12 periods. The values of the objective functional are 54.011 for scenario 1, 54.308 for scenario 2, and 54.896 for scenario 3. In all three scenarios, initial- and terminal-period disposable income are very similar; in scenarios 2 and 3, there are substantial interperiod oscillations in disposable income, but invariably only below the initial-period value; in other words, sharp downward movements do occur, but next-period upturns tend to move towards the initial-period

value rather than overshoot it. In scenario 1, the oscillations are much smaller, and disposable income values are above the initial-period value in periods 9 through 12, but decreasingly so. This additional information does suggest that the instability in the 10-period model could stem from the choice of planning horizon.

The 12-period version of scenario 2 is different in one important respect from its 10-period counterpart: whereas the latter run shows high wage rates and low unemployment rates in periods of high taxation, and vice versa, the former run registers downturns in high-tax periods and recoveries in low-tax periods. This is intuitively plausible, and is consistent with both the 10-period and the 12-period run under scenario 3.

The option to create public infrastructure is exercised under scenario 2 only in 2 periods in both the 10-period and the 12-period version; net additions to infrastructure are actually utilized (partially or fully) in 1 period in the 10-period version and in both periods in the 12-period version. Likewise, in scenario 3, the government creates additional infrastructure in 1 period in each of the two versions; in both instances, net additions are actually utilized (partially or fully) by the regional economy. The government chooses to make human capital investments (under scenario 3) in 5 periods in the 10-period version, and in 7 periods in the 12-period version.

Fragile as these findings are, they make at least a modest case for an expanded role for the local government in regional growth. The evidence may arguably be strengthened by explicitly incorporating the productivity-enhancing effects of both physical infrastructure and human capital investments. These and other possible model refinements will be discussed in Chapter 6 as potential avenues for further research, following an overview of the specific research contributions of this exercise.

CHAPTER 6
SUMMARY AND CONCLUSIONS

6.1 Overview

A brief review of the origins of this exercise may help place its contributions in perspective. Essentially, three major sources of literature are garnered in support of the general rationale. In Chapter 1, several empirical studies of regional policy effectiveness are cited so as to arrive at the following broad contentions: (i) most existing regional policy measures fail because they are attempted at the national level, without taking account of differences in regional endowments, production structures and adjustment propensities; (ii) if regional policy must be customized, it is best designed and implemented at the local level, if only because local governments are less likely to overlook the organic relationship between place and policy; (iii) development expenditures must be disaggregated by type, because economic effects are likely to vary by type; (iv) sectoral disaggregation is important, because the effects of any public expenditure type are likely to vary by sector; and (v) regional policy must be analyzed in a comprehensive and dynamic framework so as to account for potential feedback processes.

Also in Chapter 1, it is argued that existing model-based theories of regional growth, such as export base, neoclassical, and cumulative causation, are effective in describing the regional growth process, but are unable to link growth to conscious local initiative. Given favorable external demand, regions grow by virtue of some given combination of factors: resources, skilled labor, public infrastructure, and so on. There are no insights on whether or how a region might influence the creation of such a set of factors.

In Chapter 2, past applications of control theory to the general issue of regional development are reviewed, with three overriding findings: (a) most earlier models focus on the interregional allocation of public funds, rather than on allocation among alternative uses within a single region; (b) both the public and the private sector are aggregative, and there is no qualitative distinction between public and private investment; and (c) by assuming away several key components of interregional activity, the policy settings in these models fail to incorporate the endogenous behavior of all participating agents--investors, workers, consumers, producers, and policy officials.

Multiregional CGE models are relatively more detailed in their descriptions of regional structure, but lack an explicit policy orientation; like optimal control models, they fail to distinguish between the functions of public and private investment; and, they assume human capital formation to occur autonomously, at no cost to the regional government.

In an attempt to address these concerns, a conceptual optimal control framework is presented in Chapter 3, depicting a simplified regional economy governed essentially by local policy. Within the overall objective of portraying regional development as a comprehensive, dynamic and endogenous process, the specific policy issue of interest is the relative importance of human capital and physical infrastructure investments over the course of endogenous regional growth, after Hansen [1965] and Coffey and Polese [1984]. The region of policy interest has a local government that imposes a tax in the region and that uses the tax revenue to finance investments in physical infrastructure and human capital. Private activity is illustratively disaggregated into three sectors, production in each of which is a function of private capital and labor. Private investment, production, and employment in each sector, as also the regional wage rate, are endogenous. The model also allows for endogenous changes in labor supply through migration and labor force participation decisions. The local government must choose optimal time paths for the two control

variables--the tax rate and the expenditure shares of human capital and physical infrastructure investments--so as to optimize a predefined objective functional.

For purposes of implementation, an operational version is presented in Chapter 4, with the following specific features: the local government levies an income tax in the region; the region has two sectors--an export sector with an exogenous price, and a local sector with an endogenous price; the demand function in the local sector, as also an endogenous price deflator, is derived from utility maximization; production in each sector is a Cobb-Douglas function of private capital and unskilled and skilled labor; physical infrastructure acts as a constraint on overall regional production; and, as a first approximation, public human capital investment transforms unskilled workers into skilled workers. Both the unskilled and skilled wage rates are endogenous; migration permits endogenous changes in unskilled and skilled labor supply from period to period; and a partial adjustment mechanism permits endogenous changes in private capital stock in the two sectors, from period to period.

The operational model is executed as a nonlinear programming problem in GAMS 2.25, for three different versions of the public sector: (i) in scenario 1, the government collects tax revenues just sufficient to maintain a fixed level of physical infrastructure; (ii) in scenario 2, the government is able to make net additions to the region's stock of physical infrastructure; and (iii) in scenario 3, the government can use local tax revenues to make investments in physical infrastructure and/or human capital. The results reported in Chapter 5 provide some evidence in favor of an expanded role for the local government in regional growth. In scenario 3, the relative allocation of public funds to human capital investment is found to vary from period to period, whereas Hansen [1965] and Coffey and Polese [1984] recommend a decreasing share over the course of growth. For reasons to be identified in the following section, however, this finding is not offered as a conclusive refutation of their argument.

In essence, the model contains features of all the major competing theories of regional growth. Interregional factor mobility and the overall optimization framework are in the neoclassical tradition. The delineation of a driving export sector and a dependent local sector is clearly an export-base feature. The assumption of increasing returns to scale in the export sector and the accommodating role of public infrastructure are suggestive of cumulative causation. This attempt at a hybrid approach is consistent with the overall objective of seeking an improved rather than an alternative understanding of regional dynamics.

Technically speaking, the model incorporates several specific features found wanting in both optimal control and CGE models of regional growth, and may therefore be deemed a modest contribution to both those strands in the literature.

6.2 Suggestions for Future Research

The model suffers from one significant failing: as tested, it demonstrates the enabling role that local public policy can play in sustaining the growth of a region propelled by an export base mechanism. But it still begs the question of whether such policy can in fact initiate growth in a lagging region. Two reasons may be identified.

Firstly, the treatment of physical infrastructure as a constraint on regional production does not allow for its potential productivity effects. The conventional approach of including physical infrastructure as an additional factor in a Cobb-Douglas production function suffers from the associated problem of substitutability of infrastructure for other factors of production. The idea proposed in Chapter 3, that infrastructure could have private capital-augmenting or output-augmenting productivity effects, is inherently appealing, but difficult to identify and/or operationalize. As Munnell concludes, the causation issue is far from resolved, and is worthy of further research.

Secondly, the use of human capital investment merely to transform unskilled into skilled workers sidesteps a horde of underlying complexities. In Chapter 3, Salamon's five dimensions to human capital investment are noted: (i) elementary and secondary education; (ii) higher education; (iii) research and development; (iv) employment and training; and (v) supportive services (health care, nutrition, social services, and day care). In the context of a production function, it is proposed that items (i) and (v) may be considered as unskilled labor-augmenting, (ii) as both unskilled and skilled labor-augmenting, (iv) as a transformation of unskilled workers into skilled workers, and (iii) as private capital-augmenting. Thus, the formulation of human capital investment used in this study represents but one aspect of a complex and multifaceted policy instrument.

Adherence to the concept of a production function limits the ability to comprehend the full range of effects flowing from human capital investment. While educational and training investments (items (i), (ii) and (iv)) and those in supportive services (item (v)) enable people to become more efficient workers (labor inputs), they do not account for the <u>local control</u> of activities that endogenous regional growth demands. As noted earlier, in Chapter 1, Coffey and Polese [1984] describe the process as occurring in four stages: (i) the emergence of local entrepreneurship and the "take off" of local firms; (ii) growth of local firms beyond the region; (iii) emergence of a local control structure, with growing importance of locally controlled activity; and (iv) establishment of a locally controlled economic structure (p. 7).

The key notion of local entrepreneurship implies that it is not enough merely to invite more private capital into the region--the local origin of private investment becomes paramount if regions must operate at the upper end of the product life cycle. Four principal characteristics are associated with entrepreneurs: risk-taking, supplying capital, competent or perceptive management, and innovativeness (Malecki [1991], p.318).

Innovativeness is the decisive factor in the ability of local firms to grow beyond their local confines, i.e., to generate and tap external markets on a competitive footing.

Malecki [1991] identifies a list of factors that make up a region's innovative potential, including the autonomy of decision-making in the region's industries, regional infrastructure, and the technological orientation of the educational system (p. 324). Thus, research and development (R & D) expenditures (item (iii) above) become significant, and, in turn, reinforce the importance of items (i) and (ii), given their sequential relationships. Malecki [1991] endorses this by noting that "many of these shortcomings can be overcome if education levels in the population are high; education is strongly related to a greater range of information sources and a wider set of customers and markets--in short, to an awareness of industry best practice . . ." (p. 325).

Regions can be innovative either by acquiring and assimilating technology from outside, or by generating it internally. Internal generation includes public investment in (mostly) basic research, and (largely) private initiative in applied research. The former is more general in nature, and its immediate impact depends on its degree of integration with the local economy. The latter is mostly sector-specific, but transmitted or diffused within the region through intersectoral linkages. Both components demand technological capability in the form of production and non-production skills, imparted through higher education, training and experience.

A region's ability to exploit technologies developed elsewhere has four dimensions--identification, implementation or adoption, assimilation, and improvement. Each of these components represents a supplementary learning process: identification reflects "learning by searching"; implementation reflects "learning by doing", "learning by using", and "learning by training"; and assimilation and improvement reflect "learning by

changing" (Malecki [1991], pp. 146-8). Critical requirements are technological capabilities and information sources of various kinds.

Malecki [1991] emphasizes the roles of other factors in technical change as follows:

> Technological capability, although often measured by R & D effort or R & D personnel, includes a wider array of technological assets, and draws upon a wider variety of information sources, including customers and suppliers as well as in-house capabilities. Local concentrations of R & D provide an important, but not a comprehensive, indicator of regional technological capability (p. 154).

In sum, it may be said that human capital investment in any form is a necessary but not a sufficient condition for (endogenous) regional growth, and must be supported by a variety of other measures.

Besides the need for respecified impact mechanisms for physical infrastructure and human capital investments, the model permits several lesser refinements: by construction, all income generated in the region is consumed, so that there is effectively no indigenous capital accumulation. Therefore, the assumption that all payments to capital are made within the region implies the inflow of both investor and investment, and glosses over the complex nature of transboundary capital flows (see Kraybill, p. 17).

In all six runs--three scenarios each under a 10-period and a 12-period horizon--the two sectors move in opposite directions to accommodate the infrastructural constraint. Since this is at odds with the export-base conception, alternative sets of initial values for the endogenous variables may be used to examine whether and under what conditions the two sectors move upward or downward together. Such experimentation would also check whether the general downward trend in the export sector capital stock is associated with the initial values actually used.

Like public infrastructure, private capital must also be subjected to depreciation. Asymmetric downward and upward speeds of adjustment may be used to reflect the lumpiness and fixity of past physical investments.

Private investment decisions may be explicitly linked to public infrastructure levels in the region.

The specification of interregional migration may be improved by including distributed lags, moving costs and locational preferences. As a direct result of the synthetic structure of the model, all exogenous national variables are held fixed over the planning horizon. Any further application of the model would require a more realistic delineation of sectors, as also the explicit recognition of the feedback effects of public good production on the local economy; allowance must also be made for possible technical change; stochastic elements could be introduced to reflect uncertainty and limited information.

In view of the narrow tax base available to lagging regions, a balanced budget in the public sector could prove to be a stringent constraint; as such, the possibility of government debt may be worthy of inclusion.

In terms of solution strategies, the planning horizon may need to be lengthened considerably following the introduction of leads and lags in the impact mechanism of human capital investments, and alternative methods of terminating the model may be fruitfully attempted.

APPENDIX A
SUMMARY OF RESULTS BY SCENARIO

SCENARIO 1 (1 CONTROL VARIABLE: TAX RATE TO MAINTAIN FIXED STOCK OF PUBLIC PHYSICAL CAPITAL)

Variable	Time periods									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Skilled real wage	1.003	1.006	0.996	1.011	1.006	1.01	0.964	1.018	1.039	1.015
Unskilled real wage	0.699	0.701	0.692	0.704	0.699	0.702	0.665	0.708	0.725	0.705
Skilled employment, export sector (10^6)	0.6867	0.6902	0.6765	0.6932	0.688	0.6929	0.6323	0.693	0.7247	0.7044
Unskilled employment, export sector (10^6)	0.892	0.8968	0.881	0.9012	0.8956	0.9019	0.8292	0.901	0.9397	0.9172
Skilled employment, local sector (10^6)	0.6012	0.6002	0.6034	0.5983	0.6006	0.5998	0.6133	0.5934	0.5893	0.6012
Unskilled employment, local sector (10^6)	0.4512	0.4506	0.454	0.4494	0.4517	0.451	0.4647	0.4457	0.4415	0.4522
Output level, export sector (10^6)	4.726	4.7343	4.6923	4.7377	4.7214	4.7338	4.5504	4.7215	4.8123	4.7585
Output level, local sector (10^6)	3.2135	3.2186	3.2403	3.2282	3.2455	3.2497	3.3118	3.2382	3.2277	3.2815
Relative price, local sector	0.708	0.709	0.697	0.707	0.701	0.702	0.66	0.702	0.719	0.699
Price deflator	0.602	0.602	0.605	0.602	0.604	0.604	0.615	0.604	0.599	0.605
Regional disposable income (10^6)	7.5874	7.6016	7.5297	7.6075	7.5796	7.6008	7.2865	7.5798	7.7355	7.6432
Current regional income, per capita	2.616	2.622	2.595	2.63	2.614	2.62	2.507	2.643	2.685	2.615
Total regional skilled employment (10^6)	1.2879	1.2904	1.2799	1.2914	1.2886	1.2927	1.2456	1.2865	1.3139	1.3056
Total regional unskilled employment (10^6)	1.3431	1.3474	1.3351	1.3505	1.3473	1.3529	1.2939	1.3467	1.3812	1.3694
Skilled labor supply (10^6)	1.4	1.3985	1.3988	1.3943	1.3969	1.397	1.3989	1.3814	1.3873	1.4056
Unskilled labor supply (10^6)	1.5	1.5006	1.5028	1.4988	1.5033	1.5044	1.5077	1.4861	1.4942	1.5172
Skilled unemployment rate	0.08	0.077	0.085	0.074	0.078	0.075	0.11	0.069	0.053	0.071
Unskilled unemployment rate	0.105	0.102	0.112	0.099	0.104	0.101	0.142	0.094	0.076	0.097
Net migration, skilled		-3069	-1368	-6052	933	-1488	360	-19130	4286	16697
Rate of skilled net migration		-0.002	-0.001	-0.004	0.0007	-0.001	0.0003	-0.014	0.003	0.012
Net migration, unskilled		-3923	-2232	-8602	15	-3367	-1263	-26110	3684	18556
Rate of unskilled net migration		-0.003	-0.001	-0.006	1.0E-7	-0.002	-0.0008	-0.017	0.002	0.012
Private capital stock, export sector (10^5)	8	7.9931	7.9874	7.9773	7.9729	7.9665	7.9616	7.9377	7.9346	7.9407
Private capital stock, local sector (10^7)	6	6.0491	6.0971	6.1412	6.1864	6.2292	6.2713	6.302	6.341	6.3838
Public physical capital stock (10^7)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Optimal income tax rate	0.045	0.045	0.046	0.045	0.045	0.045	0.047	0.045	0.044	0.045
Optimal allocation to physical capital										
Public human capital investment (10^6)										
No. transformed unskilled - skilled										
Value of objective function										54.259

SCENARIO 2 (2 CONTROL VARIABLES: TAX RATE AND PHYSICAL CAPITAL INVESTMENT)

Variable	Time periods									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Skilled real wage	0.994	0.995	1.014	1.016	1.001	1.008	1.019	1.037	0.946	1.006
Unskilled real wage	0.691	0.691	0.708	0.708	0.695	0.701	0.71	0.725	0.645	0.698
Skilled employment, export sector (10^6)	0.6705	0.6669	0.698	0.704	0.6784	0.6947	0.7125	0.7508	0.592	0.6853
Unskilled employment, export sector (10^6)	0.8729	0.8688	0.9053	0.9135	0.8847	0.9035	0.9251	0.971	0.7856	0.8935
Skilled employment, local sector (10^6)	0.6081	0.608	0.5936	0.5929	0.6069	0.5965	0.591	0.5769	0.6517	0.6038
Unskilled employment, local sector (10^6)	0.4574	0.4576	0.4448	0.4445	0.4573	0.4482	0.4434	0.4311	0.4996	0.4549
Output level, export sector (10^6)	4.6783	4.6634	4.75	4.7674	4.6937	4.7375	4.7872	4.8957	4.4322	4.6994
Output level, local sector (10^6)	3.2397	3.2487	3.2019	3.2076	3.2697	3.2377	3.223	3.175	3.4725	3.2926
Relative price, local sector	0.703	0.701	0.711	0.709	0.699	0.698	0.704	0.712	0.655	0.691
Price deflator	0.603	0.604	0.601	0.602	0.605	0.605	0.603	0.601	0.616	0.607
Regional disposable income (10^6)	7.5889	7.5873	7.5848	7.5824	7.6138	7.5364	7.5655	7.5365	7.5792	7.5852
Current regional income, per capita	2.617	2.625	2.632	2.621	2.621	2.597	2.605	2.581	2.563	2.611
Total regional skilled employment (10^6)	1.2785	1.2749	1.2916	1.2969	1.2852	1.2912	1.3034	1.3276	1.2437	1.2891
Total regional unskilled employment (10^6)	1.3303	1.3264	1.3501	1.358	1.342	1.3518	1.3685	1.4021	1.2852	1.3484
Skilled labor supply (10^6)	1.4	1.3951	1.3906	1.3946	1.3991	1.3974	1.398	1.404	1.419	1.3981
Unskilled labor supply (10^6)	1.5	1.4954	1.491	1.4984	1.5063	1.5043	1.5067	1.5159	1.538	1.5073
Skilled unemployment rate	0.087	0.086	0.071	0.07	0.081	0.076	0.068	0.054	0.124	0.078
Unskilled unemployment rate	0.113	0.113	0.094	0.094	0.109	0.101	0.092	0.075	0.164	0.105
Net migration, skilled		-6544	-6023	2350	2952	-3373	-935	4324	13409	-22540
Rate of skilled net migration		-0.005	-0.004	0.002	0.002	-0.002	-0.0007	0.003	0.01	-0.016
Net migration, unskilled		-9108	-8878	2966	3403	-6532	-2133	4642	17556	-35270
Rate of unskilled net migration		-0.006	-0.006	0.002	0.002	-0.004	-0.001	0.003	0.012	-0.023
Private capital stock, export sector (10^5)	8	7.9889	7.9775	7.9747	7.9728	7.964	7.9589	7.9586	7.967	7.9338
Private capital stock, local sector (10^7)	6	6.0492	6.0967	6.1426	6.1869	6.2308	6.2708	6.3104	6.3478	6.3854
Public physical capital stock (10^7)	1.2	1.1942	1.1868	1.1903	1.1959	1.1903	1.1956	1.2046	1.2284	1.1928
Optimal income tax rate	0.038	0.036	0.049	0.052	0.038	0.052	0.056	0.074	0.002	0.042
Optimal allocation to physical capital										
Public human capital investment (10^6)										
No. transformed unskilled - skilled										
Value of objective function										54.308

SCENARIO 3 (3 CONTROL VARIABLES: TAX RATE, PHYSICAL CAPITAL AND HUMAN CAPITAL INVESTMENT)

Variable	Time periods									
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
Skilled real wage	0.987	1.011	1.016	1.025	1.017	0.993	0.972	1.021	0.999	0.957
Unskilled real wage	0.686	0.708	0.711	0.716	0.71	0.691	0.678	0.709	0.696	0.661
Skilled employment, export sector (10^6)	0.6671	0.6989	0.7091	0.7189	0.7231	0.6853	0.6812	0.6865	0.6899	0.6077
Unskilled employment, export sector (10^6)	0.8682	0.9031	0.9168	0.9309	0.9369	0.8909	0.8835	0.8949	0.8955	0.7962
Skilled employment, local sector (10^6)	0.6037	0.5946	0.5916	0.5952	0.5919	0.6122	0.5879	0.6187	0.6028	0.6422
Unskilled employment, local sector (10^6)	0.454	0.4439	0.4419	0.4453	0.4431	0.4598	0.4406	0.466	0.4521	0.4861
Output level, export sector (10^6)	4.6675	4.7526	4.7825	4.813	4.8271	4.7169	4.6981	4.7131	4.7181	4.4652
Output level, local sector (10^6)	3.224	3.1937	3.1916	3.2136	3.2106	3.2937	3.2111	3.3307	3.2788	3.4342
Relative price, local sector	0.693	0.712	0.712	0.72	0.708	0.691	0.656	0.719	0.687	0.662
Price deflator	0.606	0.601	0.601	0.599	0.602	0.606	0.616	0.599	0.608	0.614
Regional disposable income (10^6)	7.4497	7.5799	7.5764	7.7137	7.5748	7.5919	7.0259	7.9858	7.504	7.5823
Current regional income, per capita	2.569	2.63	2.619	2.653	2.584	2.577	2.394	2.755	2.57	2.602
Total regional skilled employment (10^6)	1.2708	1.2935	1.3006	1.3141	1.315	1.2975	1.2691	1.3053	1.2927	1.2499
Total regional unskilled employment (10^6)	1.3222	1.347	1.3587	1.3762	1.38	1.3507	1.324	1.3609	1.3475	1.2822
Skilled labor supply (10^6)	1.4	1.3962	1.3985	1.4029	1.4128	1.4225	1.4164	1.398	1.4104	1.4123
Unskilled labor supply (10^6)	1.5	1.4864	1.4943	1.5042	1.5191	1.523	1.518	1.5011	1.5098	1.5021
Skilled unemployment rate	0.092	0.074	0.07	0.063	0.069	0.088	0.104	0.066	0.083	0.115
Unskilled unemployment rate	0.119	0.094	0.091	0.085	0.092	0.113	0.128	0.093	0.107	0.146
Net migration, skilled		-10450	772	2815	8218	2940	-7703	-20100	8765	-5613
Rate of skilled net migration		-0.007	0.0006	0.002	0.006	0.002	-0.005	-0.014	0.006	-0.004
Net migration, unskilled		-13080	3412	5467	10411	4520	-9570	-21450	6190	-6260
Rate of unskilled net migration		-0.009	0.002	0.004	0.007	0.003	-0.006	-0.014	0.004	-0.004
Private capital stock, export sector (10^5)	8	7.9866	7.9835	7.9825	7.9849	7.9857	7.9758	7.9596	7.957	7.9489
Private capital stock, local sector (10^7)	6	6.0447	6.0921	6.1379	6.1866	6.2293	6.2711	6.2933	6.3457	6.3809
Public physical capital stock (10^7)	1.2	1.186	1.1902	1.198	1.1997	1.1956	1.1944	1.2305	1.1936	1.179
Optimal income tax rate	0.049	0.05	0.054	0.046	0.061	0.044	0.093	0.008	0.052	0.007
Optimal allocation to physical capital	0.57	1	1	1	0.652	1	1	0	0.52	0.439
Public human capital investment (10^5)	1.6599	0	0	0	1.708	0	0	0.6571	1.962	0.2844
No. transformed unskilled - skilled	5038	0	0	0	5180	0	0	2058	5903	902
Value of objective function										54.632

APPENDIX B
BEHAVIOR OF KEY VARIABLES ACROSS SCENARIOS

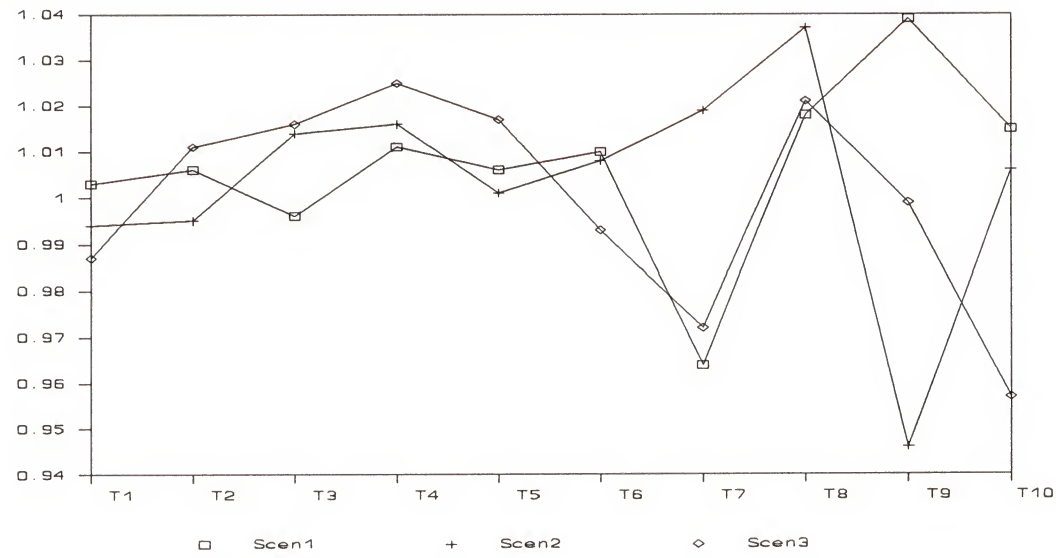

Figure B.1 Skilled real wage

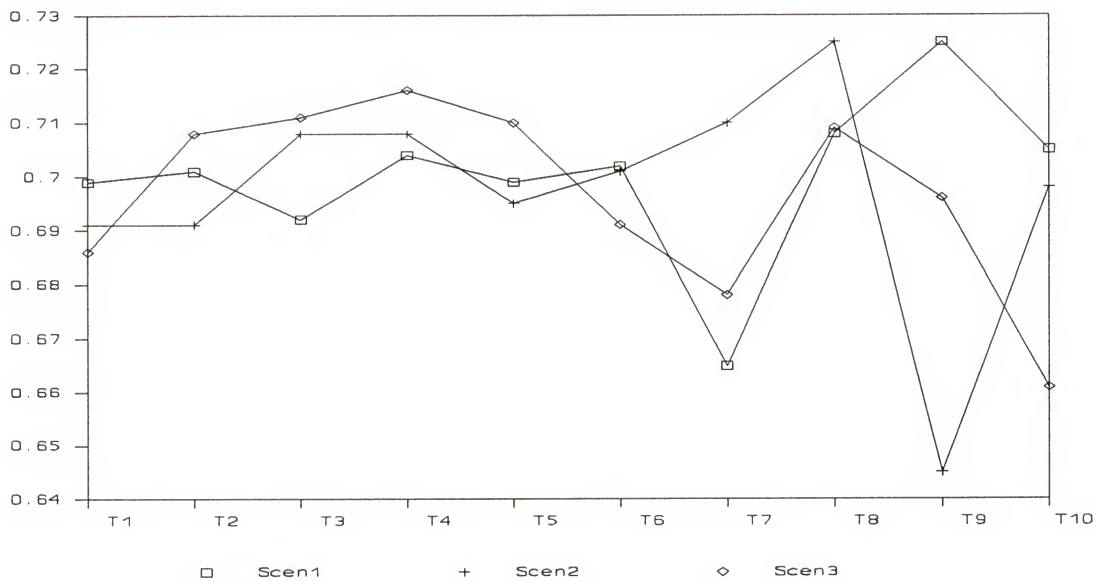

Figure B.2 Unskilled real wage

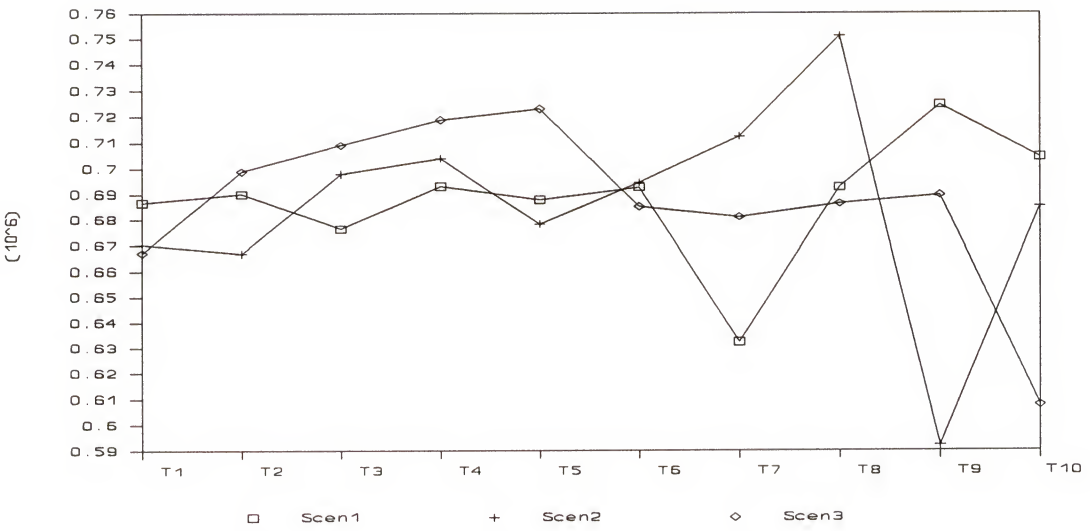

Figure B.3 Skilled employment, export sector

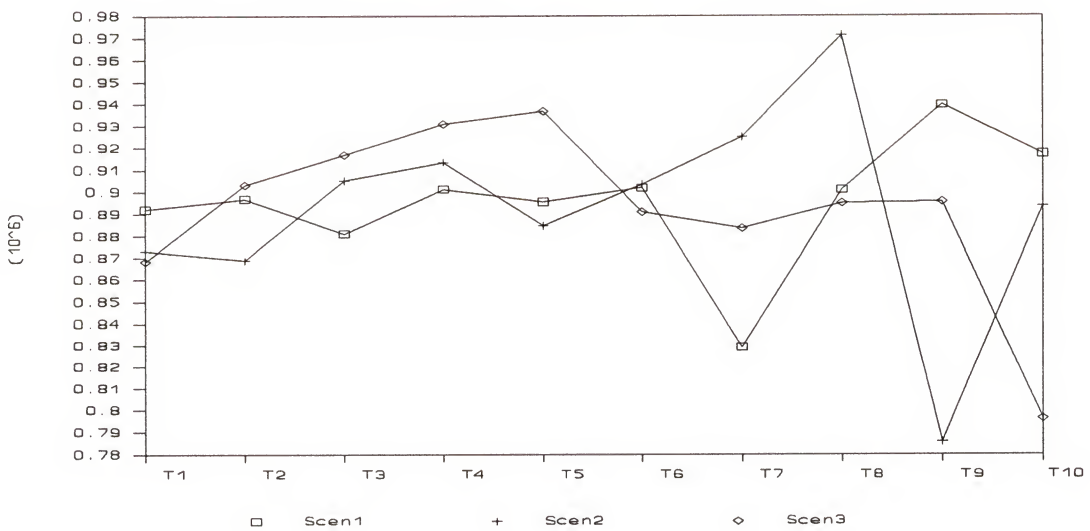

Figure B.4 Unskilled employment, export sector

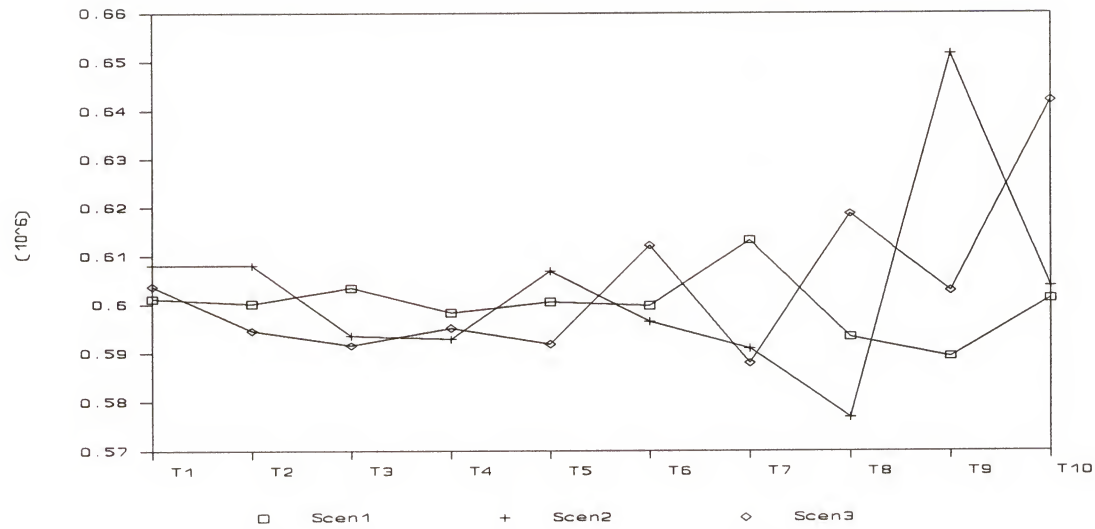

Figure B.5 Skilled employment, local sector

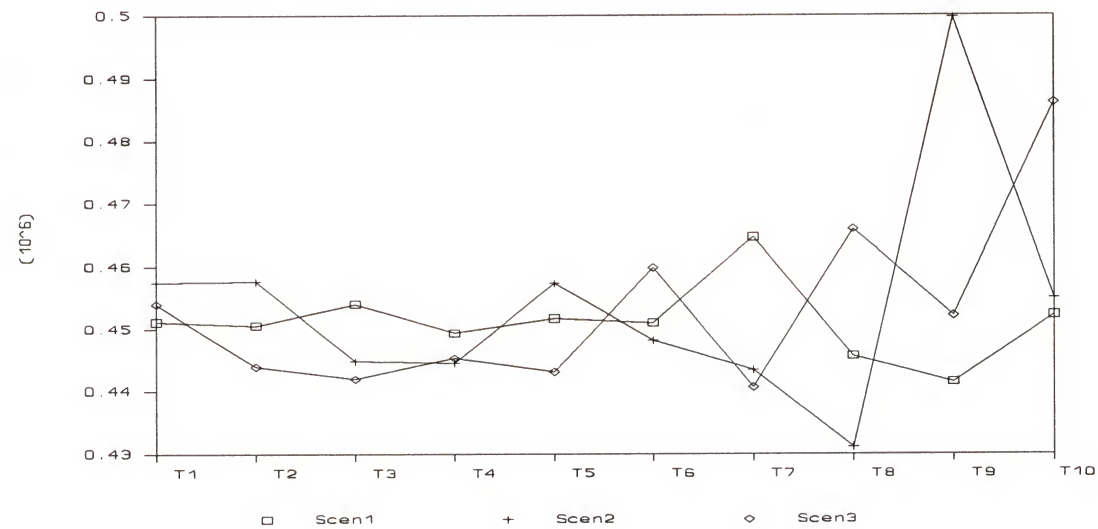

Figure B.6 Unskilled employment, local sector

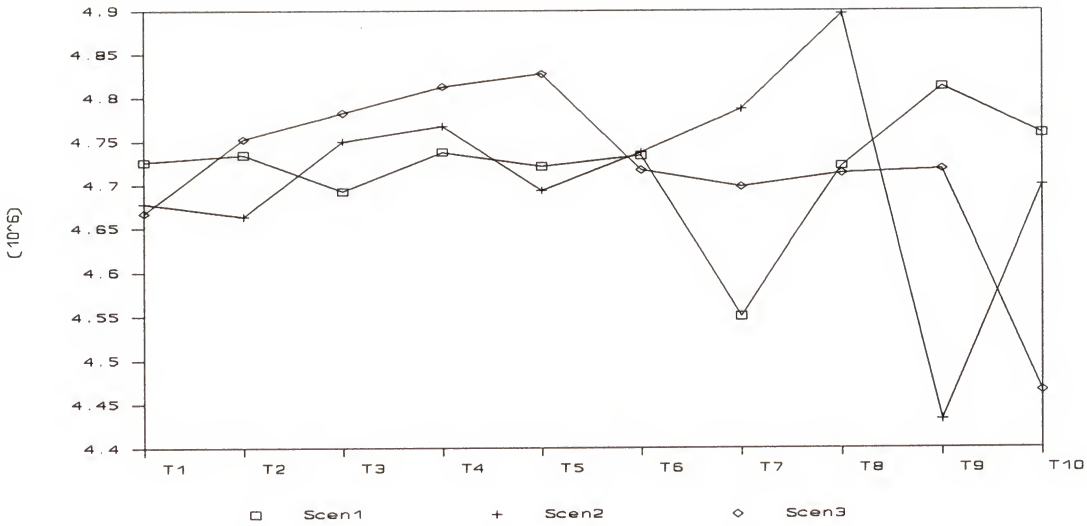

Figure B.7 Output level, export sector

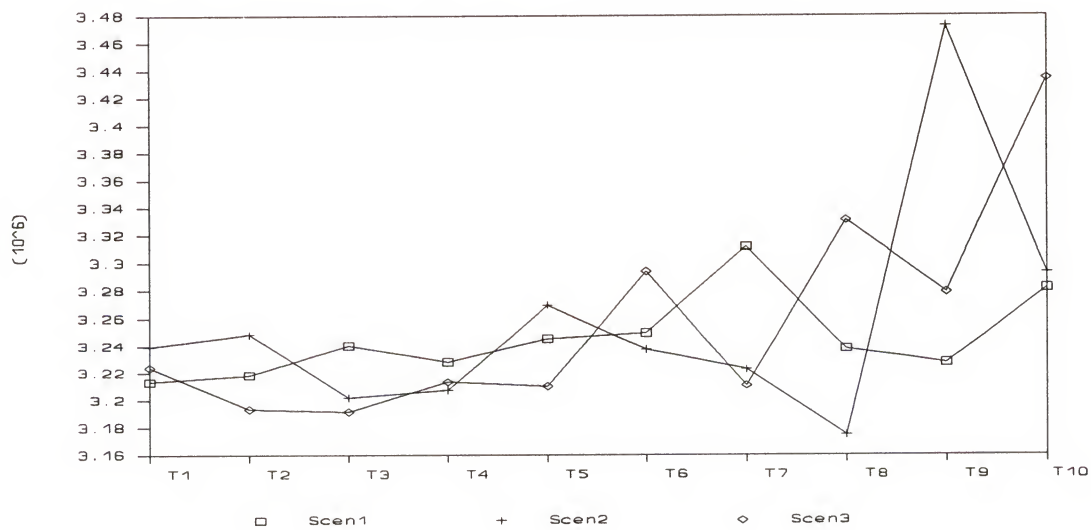

Figure B.8 Output level, local sector

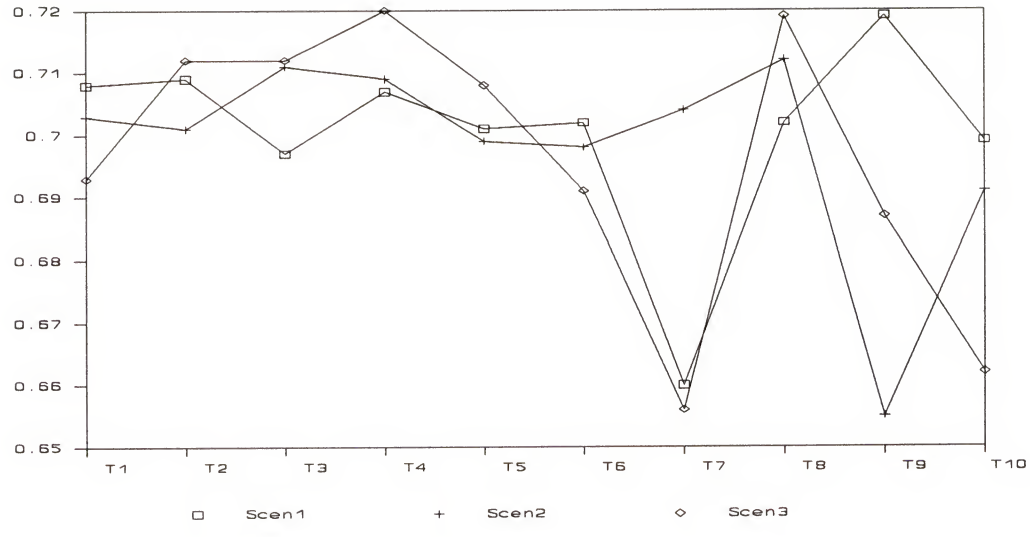

Figure B.9 Relative price, local sector

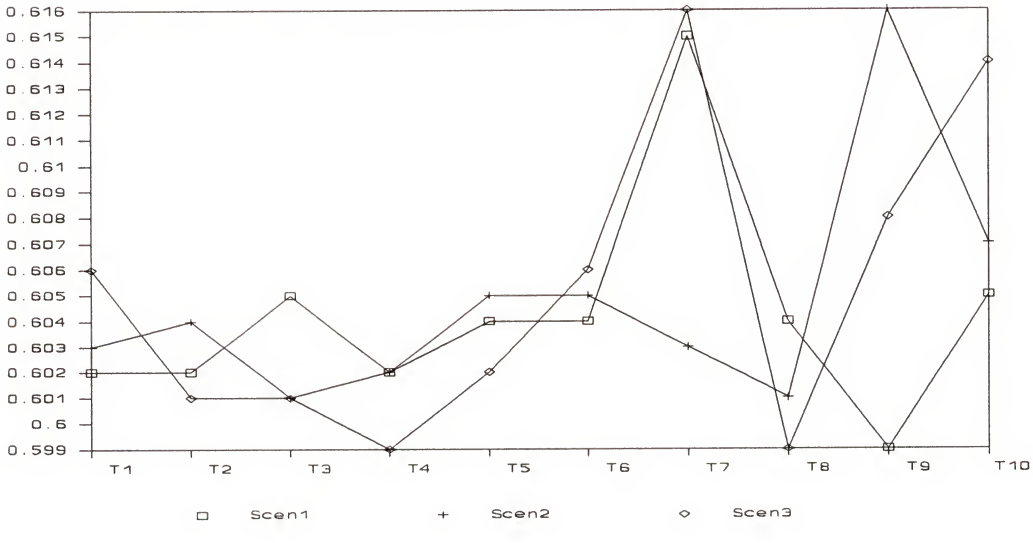

Figure B.10 Price deflator

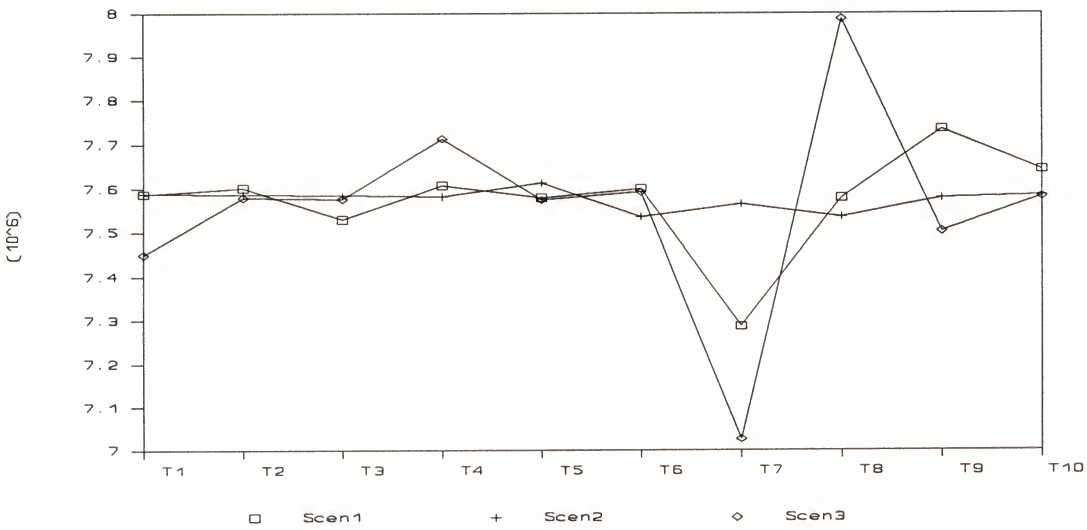

Figure B.11 Regional disposable income

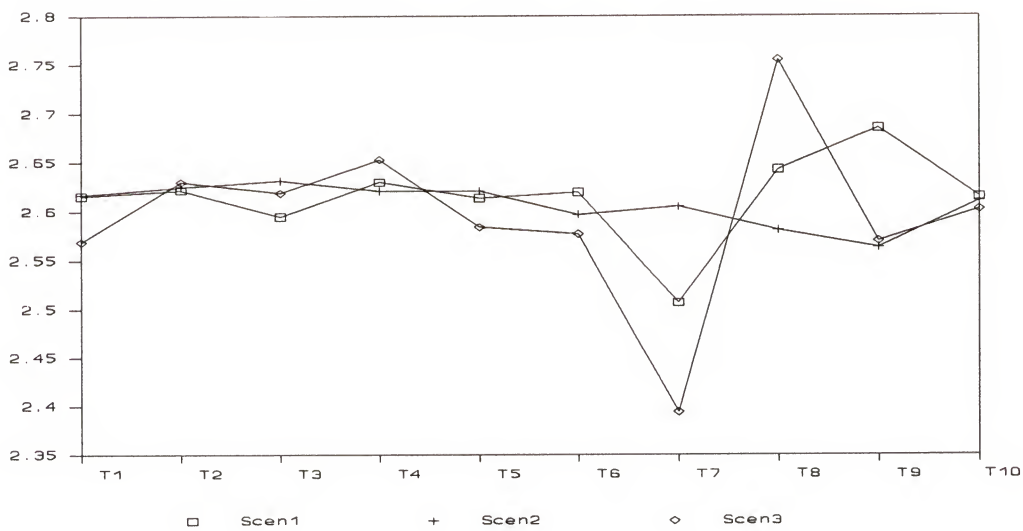

Figure B.12 Current regional income, per capita

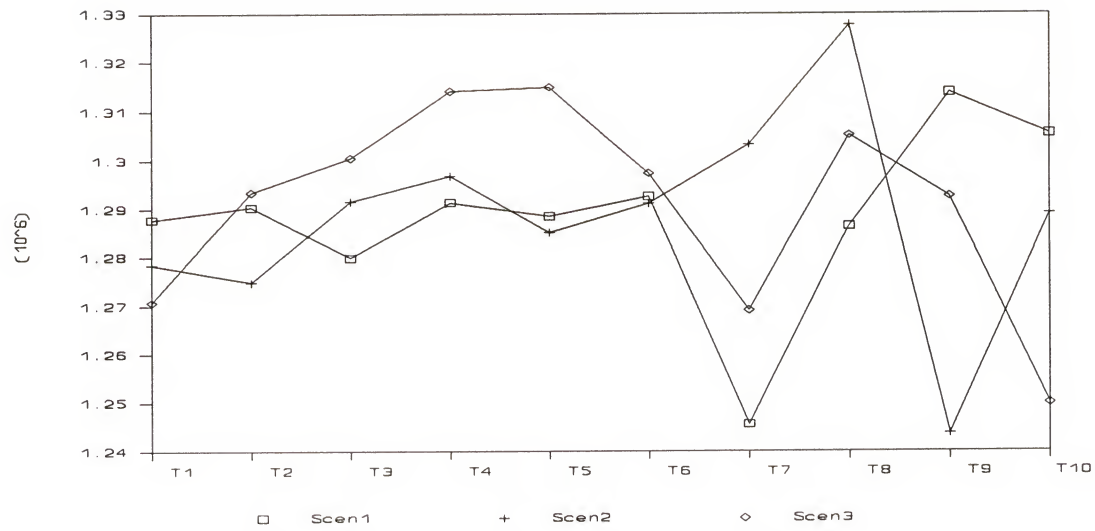

Figure B.13 Total skilled employment

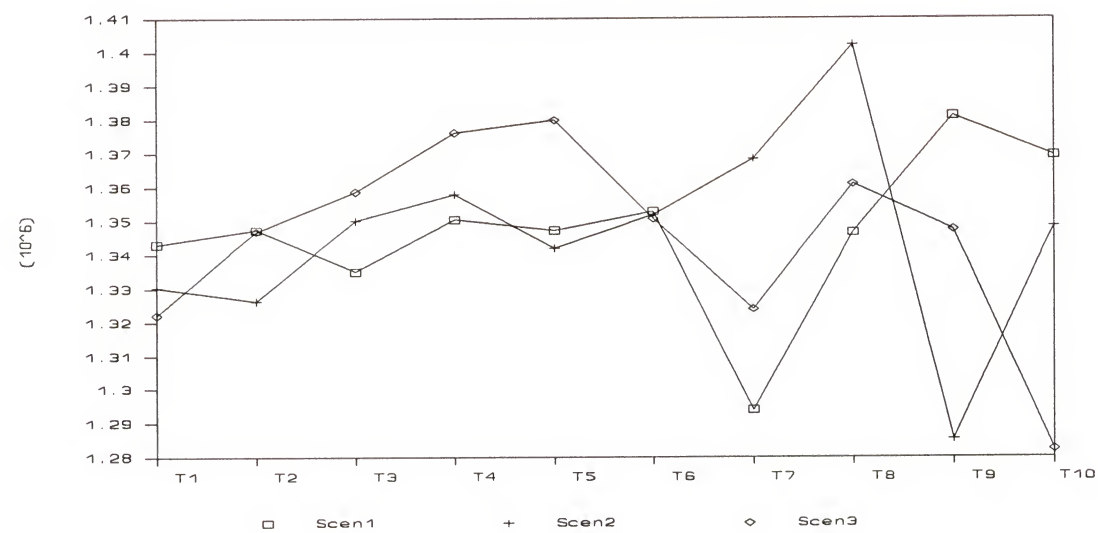

Figure B.14 Total unskilled employment

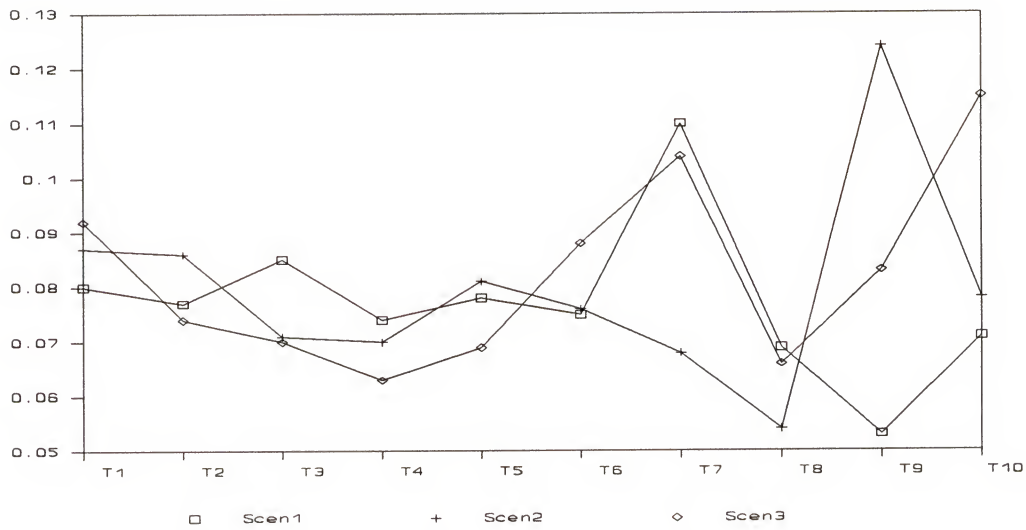

Figure B.15 Skilled unemployment rate

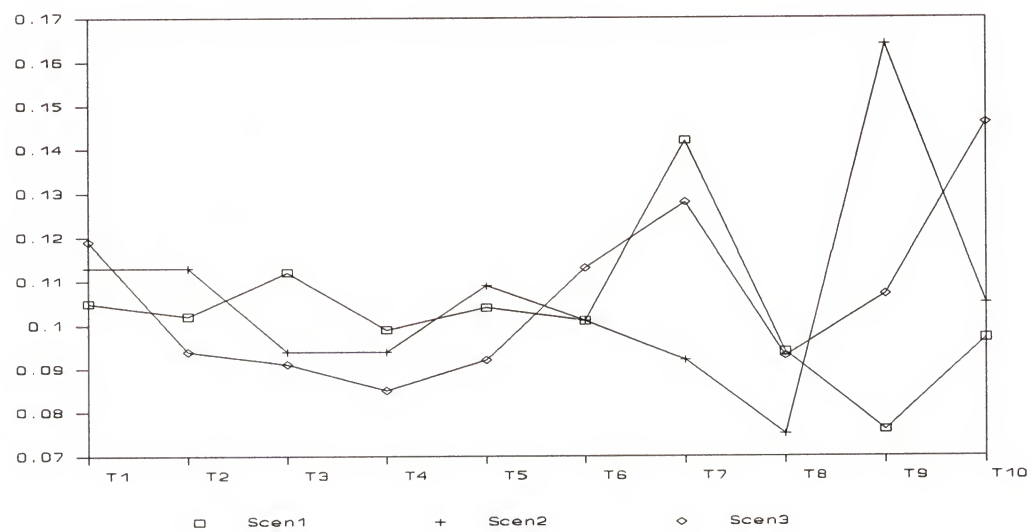

Figure B.16 Unskilled unemployment rate

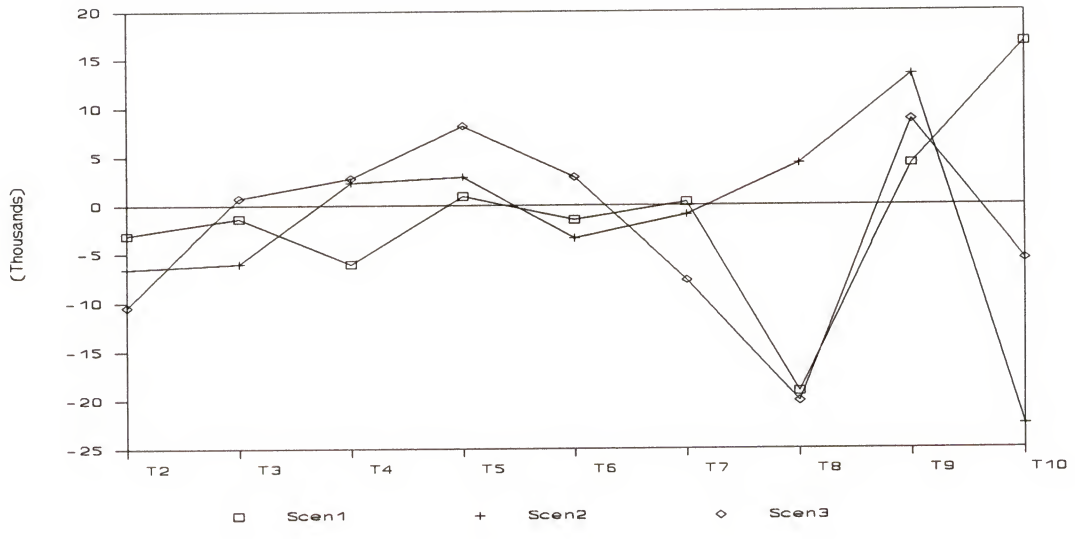

Figure B.17 Net migration, skilled

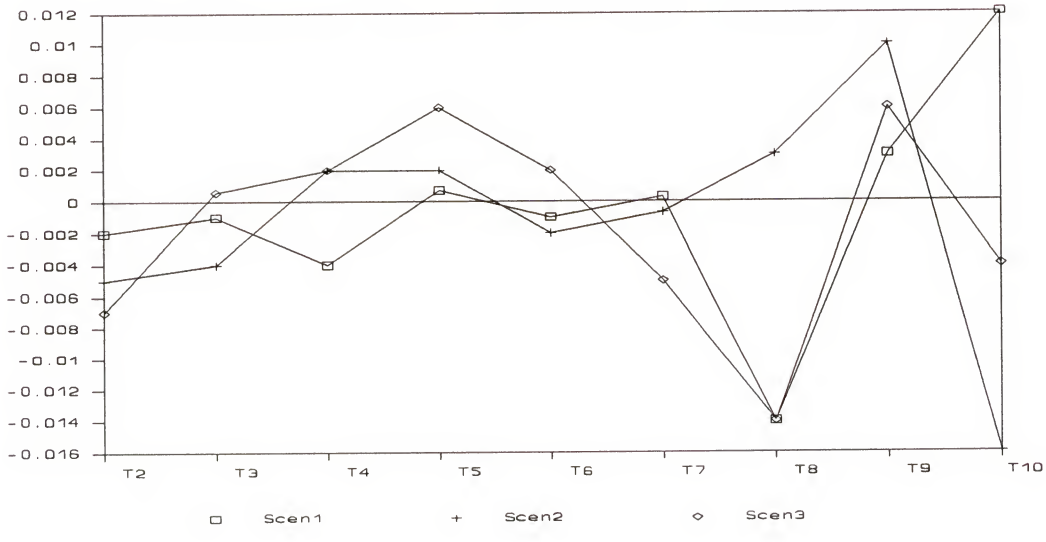

Figure B.18 Rate of skilled net migration

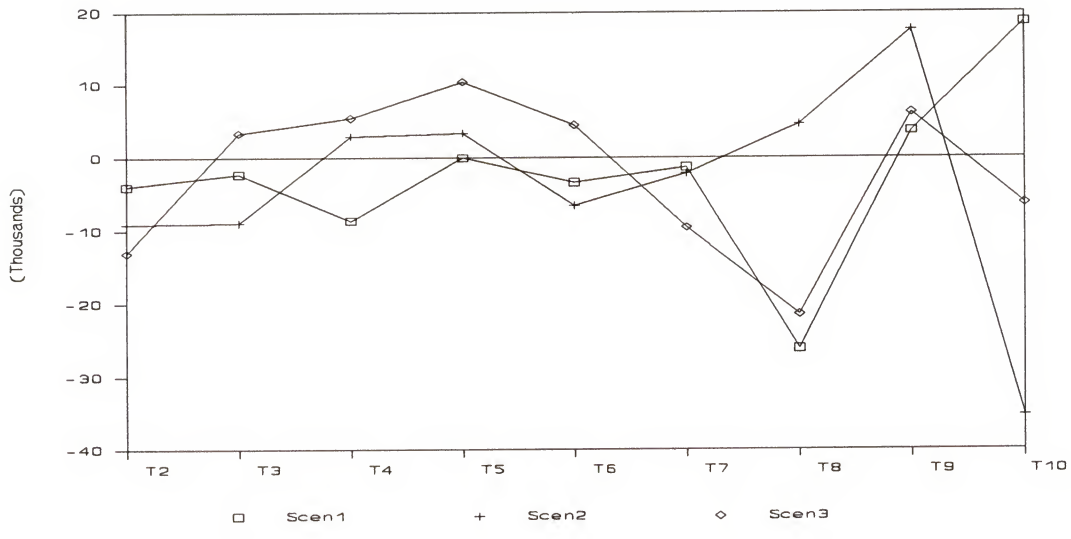

Figure B.19 Net migration, unskilled

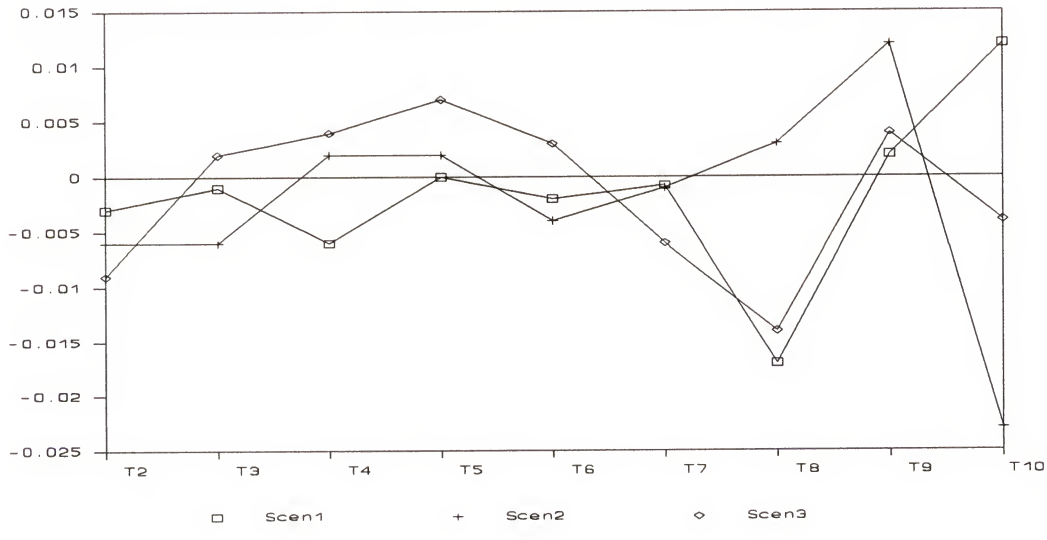

Figure B.20 Rate of unskilled net migration

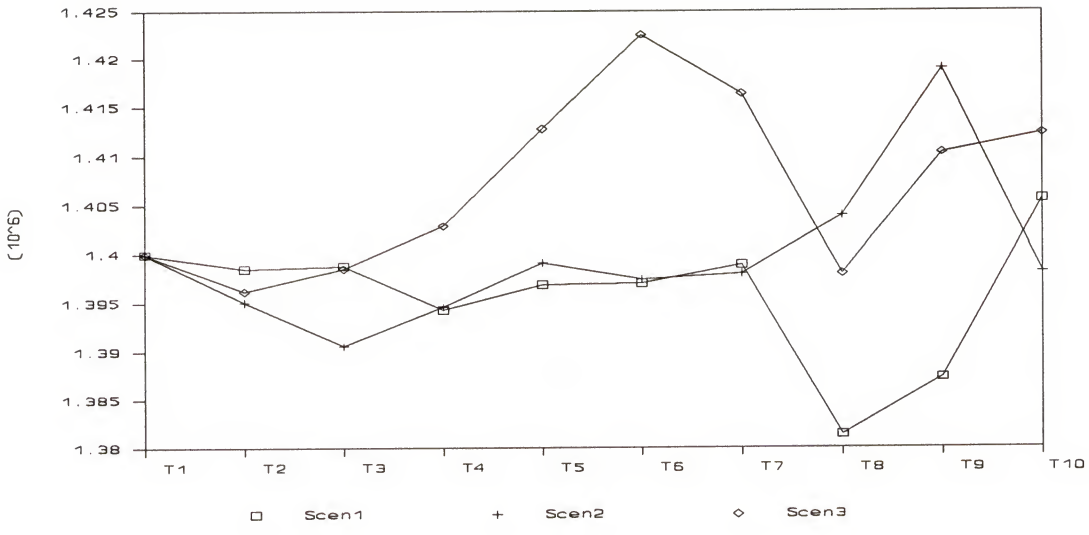

Figure B.21 Skilled labor supply

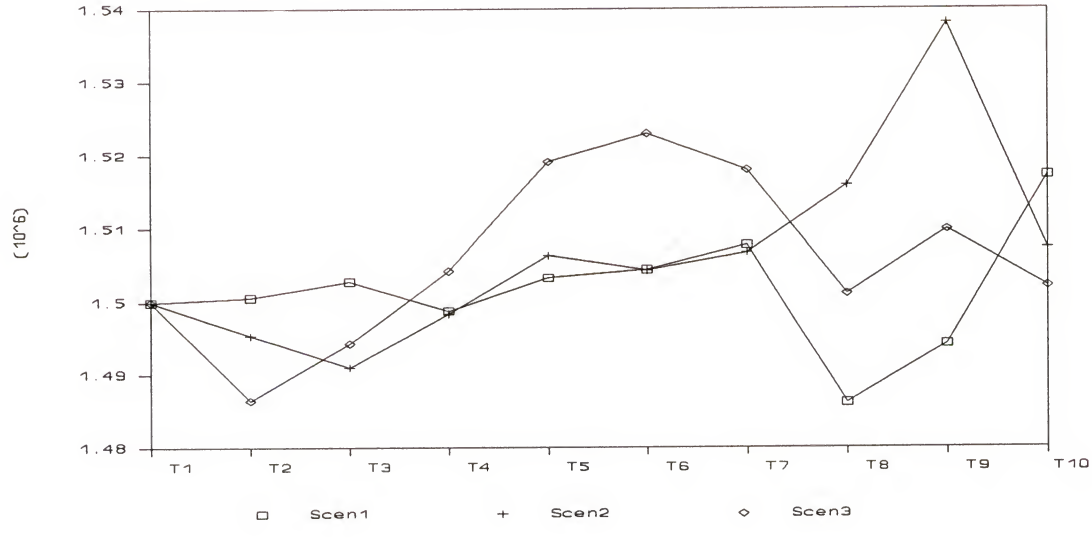

Figure B.22 Unskilled labor supply

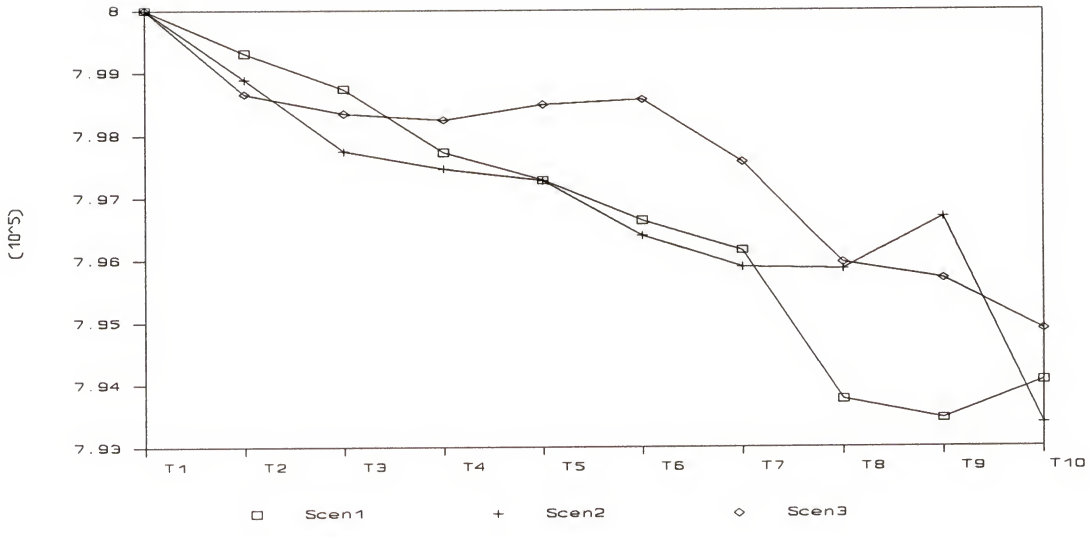

Figure B.23 Private capital stock, export sector

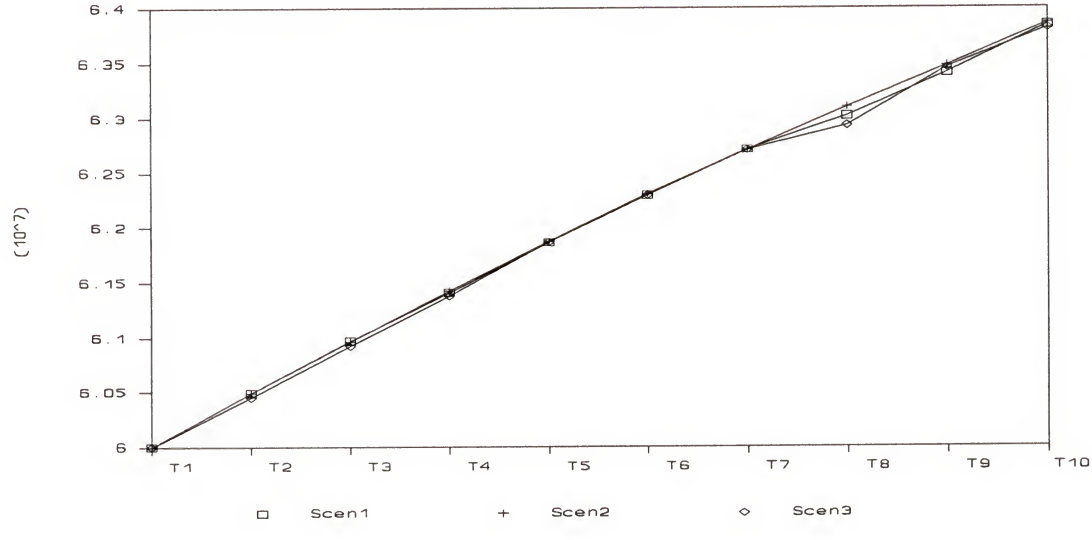

Figure B.24 Private capital stock, local sector

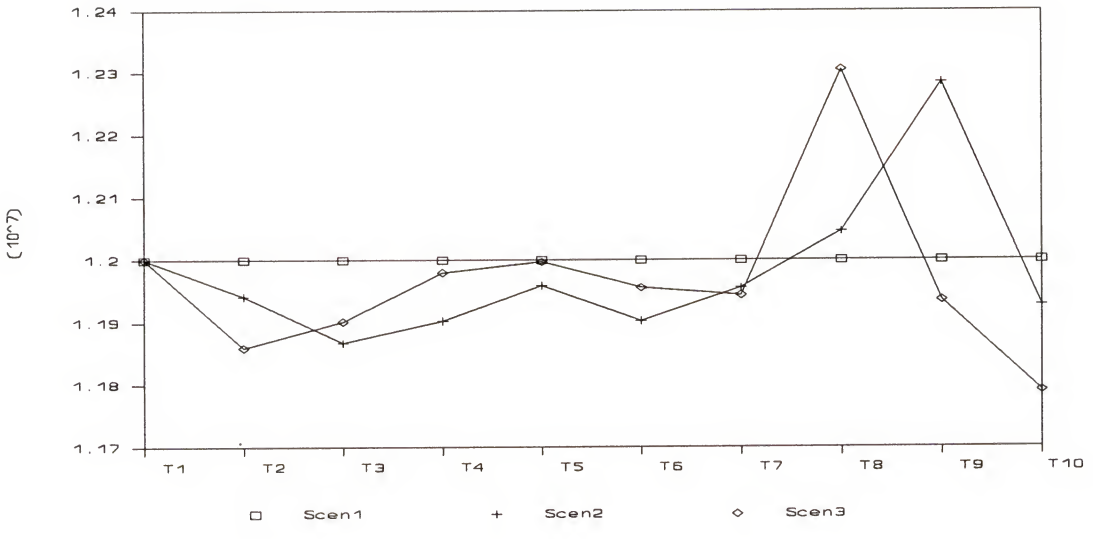

Figure B.25 Public physical capital stock

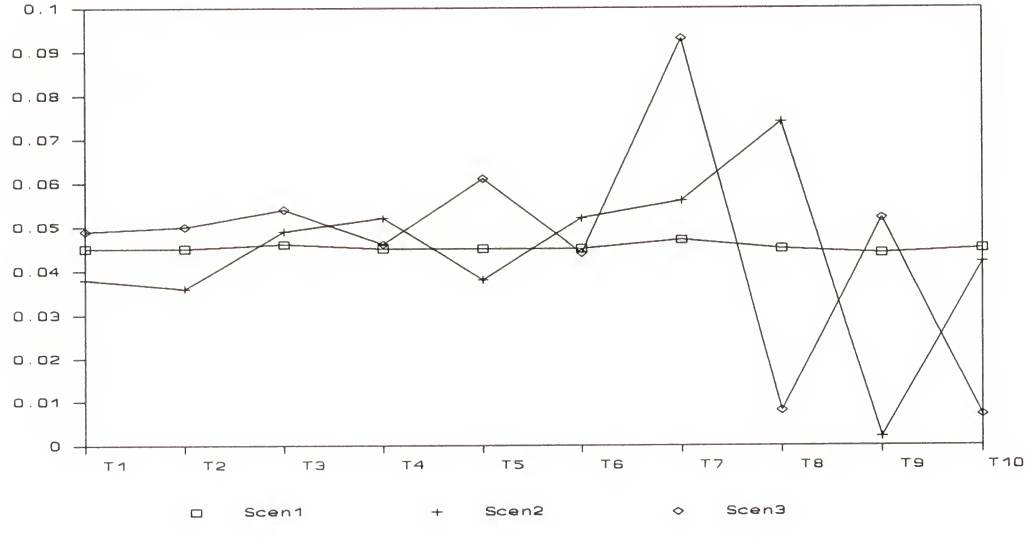

Figure B.26 Optimal income tax rate

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M. S. Deepak underwent a five-year integrated program at the Birla Institute of Technology and Science, Pilani (Rajasthan), India, to receive the M.A. (Honors) degree in economics in December 1981 (with no bachelor's degree en route).

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He served as Assistant Development Officer with India's apex policy-making body in rural development, the National Bank for Agriculture and Rural Development, from November 1984 until August 1988. During that period, he gained first-hand experience in development administration through a variety of assignments, including postsanction evaluation of projects, presanction feasibility studies, monitoring of ongoing projects and related field work, and policy-related research studies.

Mr. Deepak enrolled himself as a full-time doctoral student at the University of Florida in the Fall of 1988.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

David Mulkey, Chair
Professor of Food and Resource Economics

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December 1993

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